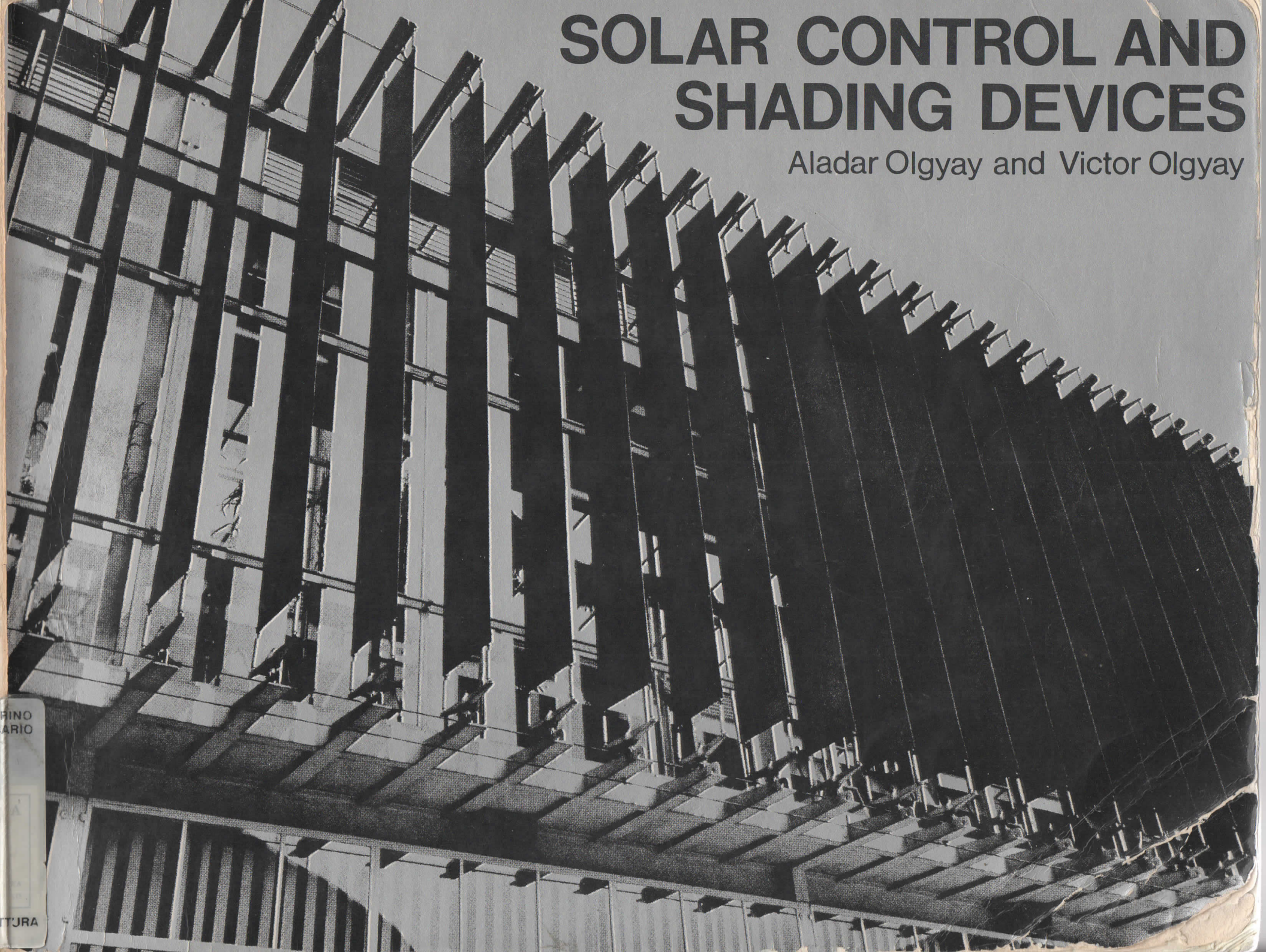
SOLAR CONTROL AND SHADING DEVICES

Aladar Olgyay and Victor Olgyay



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SOLAR CONTROL & SHADING DEVICES

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Olgyay & Olgyay

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FOREWORD

IT IS indeed seldom that a specialized subject can be considered independently. Usually it is allied to and embodied in an order of principles, and its field is generally an integral part or a reflection of some broader conception. This may be especially true of this publication.

The authors have been preparing for some years a treatise concerning the climatic environmental influences on regional architectural character. The present publication is really an offspring of this concept. In the process of evolving solar control aspects, theoretical considerations yielded some interesting details and solutions. Examples studied showed a great variety, in fact, a new vocabulary of architectural expression. Thus as the material grew it suggested an entity, a theme itself.

The architect, as new problems arise, has to maintain a balance between feeling and knowing. To fulfill his role in the relatively new problem of solar control the designer has to ponder objectively his method of approach and only then should he turn to the possibilities which lie in the visual play of light and shadow.

The intention of this publication is to clarify some of the underlying principles of shading methods and by doing so to secure a solid ground for emotional interpretation.

Accordingly this book partly deals with theoretical aspects, partly illustrates architectural examples. The material is divided into four parts. The first discusses in general the role of shading devices as architectural elements. The second describes the technical considerations involved in the design of solar protection. Part 3 summarizes the shading method in practical application. The last part illustrates the visual expressions of sun-breakers by architectural examples.

The conception of the present shading principle was outlined first in an article called "The Temperate House," and consequently enlarged in a research project for the Housing and Home Finance Agency. The approach was broadened, improved and brought to a full concept at the Architectural Laboratory of Princeton University's School of Architecture.

The work was greatly aided by a grant of the Simon Guggenheim Foundation. The publication reflects some of the beliefs of Robert W. McLaughlin, Director of the Princeton School of Architecture, who favored and encouraged research explorations, and whose views can be best epitomized with his own words ". . . we believe that architects must dig deeply into the technical areas and possibilities of their time, understand them and then through the design process mold them in the light of values other than technical or material. . . ." He supported this stand both factually and with understanding which helped this publication mature to its present appearance.

Sincere thanks are due to the institutions and to the architects who collaborated, kindly making available their material for publication purposes. Similarly grateful appreciation should be extended to colleagues of the faculty, especially to Francis A. Comstock, Associate Director of the School of Architecture for his advice and careful editorial work, and to those students who in some phase contributed to the composition of this publication by drafting.

The authors prefer to sign this publication in the same cooperative spirit they use in their work.

Olgyay & Olgyay –

Princeton, 1957

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PART 1 THEORETICAL CONSIDERATIONS

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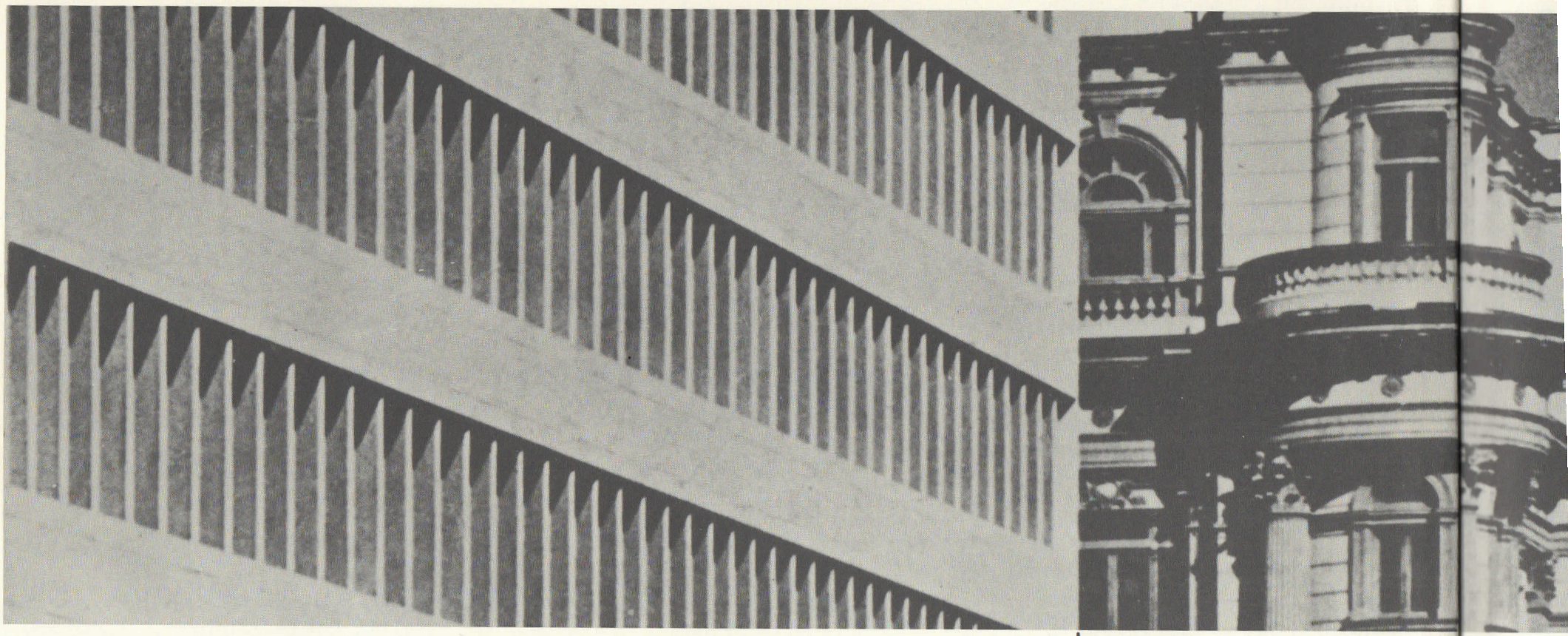
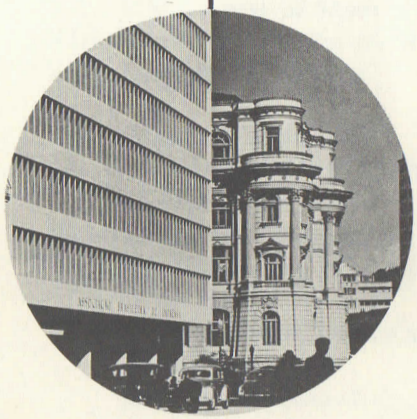


1. M.M.M. Roberto, A.B.I. building, Rio de Janeiro.



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"The sun control device has to be on the outside of the building, an element of the facade, an element of architecture. And because this device is so important a part of our open architecture, it may develop into as characteristic a form as the Doric column."

MARCEL BREUER

I. GENERAL INTRODUCTION

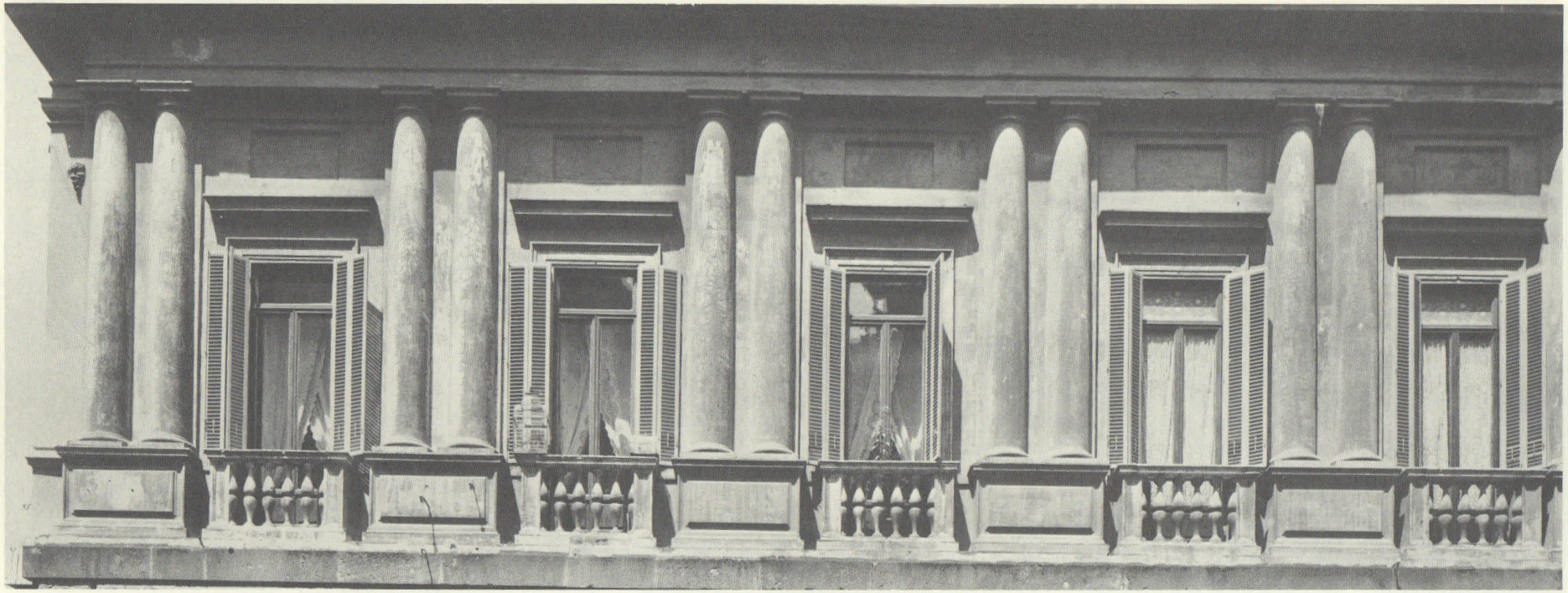
THE neighboring buildings shown above look like models for a battle of design. Each is a product of a school of discipline which expresses its own order. The picture does not wish to evaluate the different emotional convictions which resulted in these esthetic decisions—only to document their diversity.

That this happens to be in Rio de Janeiro is not important. The point lies in the fact that this could easily be anywhere. It is evidence that exteriors have undergone a change which tends to express principles in its own language.

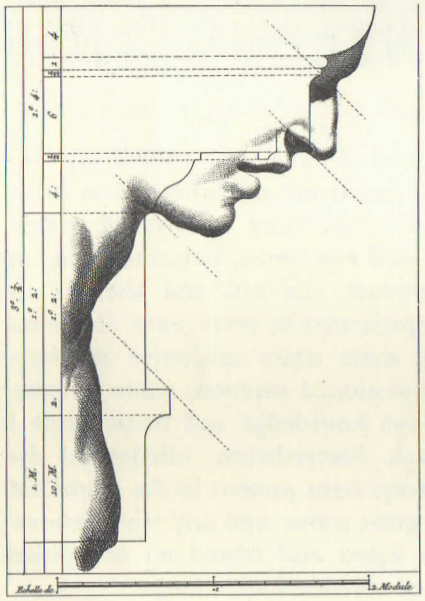
One wears the hallmarks of well-trained academic planning, while the other is an expression of principles which call for purity in lines and abstract order. Through a realization of the analogy between any epidermis and the "skin" of a building, the elevations moved toward the role of a selecting filter. This concept of the wall as a screen for environmental impacts expresses itself somewhat beyond a direct reflection of rational order. The wall becomes the domain of sensuous experimentation and the field of "dialogue" between pragmatic analysis and personal interpretation.

As emotions enter into this interplay, the sun-breakers become architectural elements.

In architecture, as in human actions, the parts of knowing and feeling are indivisibly embodied. Visual forms are a manifestation of an intricate balance of many interwoven creeds, both rational and emotional, conscious and unconscious. However, the arts and sciences are not equally represented in every wave of human aspiration. In some styles subjective emotions lead with unquestioned sureness, while in other periods objective knowledge and truth guide a secure approach. Nevertheless, intellectual discipline has always been present in the emotional expression of great styles; and any true, rational approach was based and reared on the power and strength of restricted emotions.



2. Detail of Palazzo Vidoni-Cafarelli, Rome, Raphael archt., 1515.



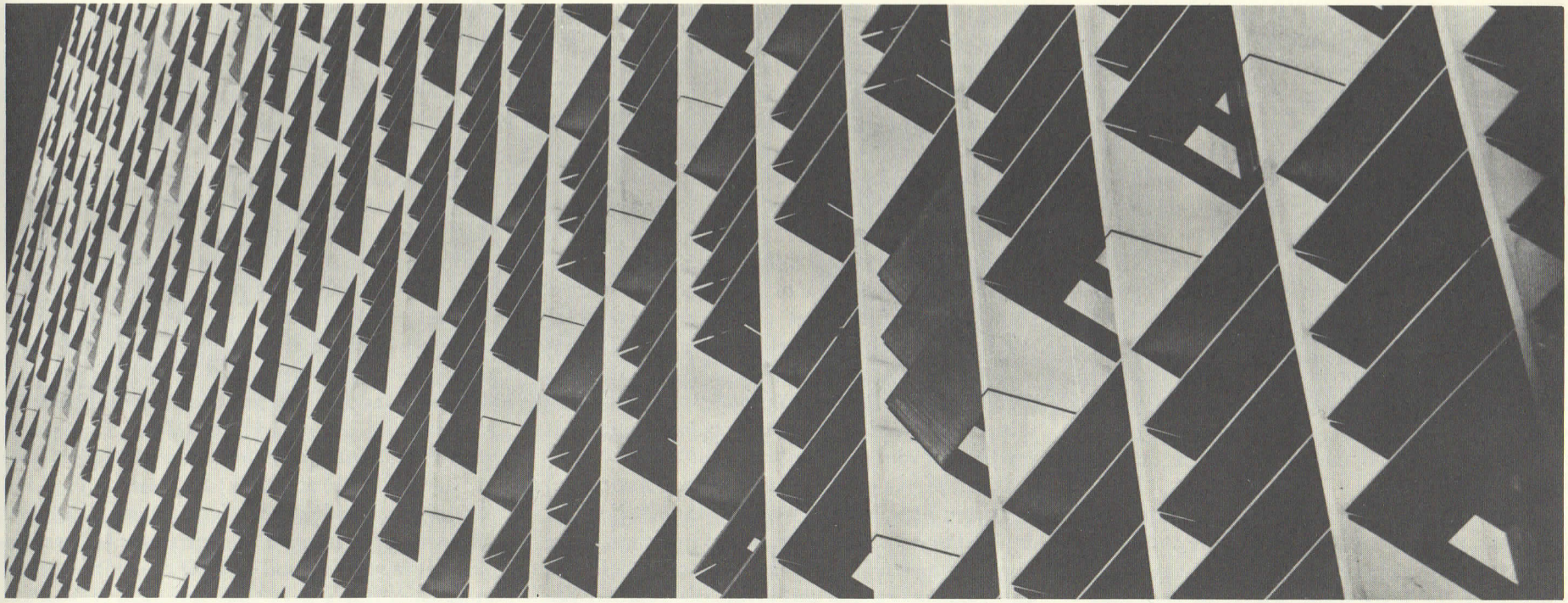
3. After J.F. Blondell, 1750.

Even in periods when elevations were governed by the brilliant play of light and shadow and were molded into form through esthetic decisions—there was the urge for order, the human desire to crystallize and strengthen subjective evaluations by projecting them into the realm of abstraction. Such is Blondell's drive as he compares a Tuscan overhang with a profile of a youth in his "Cours d'Architecture." His approach is direct and human. His comparison with its applied unrealistic scale does not lack a certain curious Stendhalesque appeal, as the effort plays half in the abstract, half in the human world. The relationships are direct: measurable by our own visual experience. The measurements are based on a "Module" applied to proportions.

Today's approach is quite different. The forces which gave birth to the modern movement draw their energies partly negatively from disappointment in anemic symbols and from the inadequacy of their existing principles to cope with the problems which emerged.

More important, positive energy is the result of a thorough reevaluation of man's relation to his surroundings. Deeper insight into nature's intricate behavior opened a new vista in man's perspective, just as a more intelligible understanding of some of its phenomena has resulted in a remarkable progress in sciences from biology to physics.

A recognition of the immensity of correlated order, the unalterable reign of basic laws which are manifested in the system of the universe, could not remain unnoticed and unappreciated in parallel approaches.



4. Niemeyer, Reidy, Costa & others, Ministry of Education, Rio de Janeiro.

This discipline of the neighboring sciences had its inductive action in architectural thinking. New problems were posed by new materials, changed issues, and novel questions from fields as diverse as physiology and sociology. They were faced with the cleanness of logic. Answers were formulated in a universal and impersonal way, evaluated through the lens of impartial objectivism. The solutions bear the impact of a drive toward a precision which is reminiscent of technical perfection.

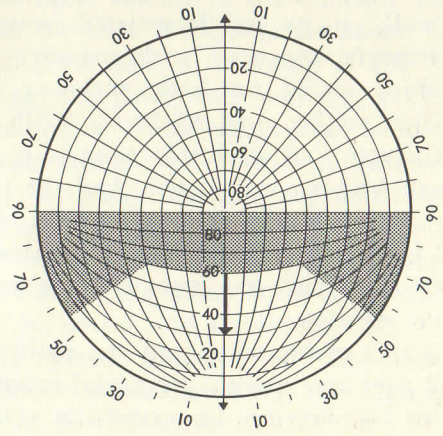
At the same time, the belief has strengthened that the right approach to a problem does not necessarily lie at the level perceptible directly to the human sensory scale.

Aesthetic thought has responded to the vitality of this new outlook and developed new proportions, new forms and new feelings to suit novel requirements, and to use new materials.

This attitude differs from the one shown on the opposite page. There, feelings were dressed with a coat of logic; whereas now abstract thinking forms a basis for the emotional content.

Here the module stems not from visual proportions, but is correlated with the movements of the sun and formulated to satisfy man's biological needs. With this approach, new elements evolve, which, through better interpretation of the underlying principles, offer a more positive foundation for the play of emotional expressions.

Man, with his intricate physical and emotional needs, remains the module—the central measure—in all approaches. The success of every design must be judged by its total effect on the human environment.



5. Evaluation with shading protractor.

Architectural expression is organic and behaves in a manner somewhat similar to the great coordinator, nature. There, every created being is the result of composite forces—and any form is representative of complex environmental adaptations. If there is a change in some of these environmental factors, a mutation of form follows by necessity. Similarly in the structure of architectural philosophy each discipline is based on underlying principles and conditions. If any new change occurs either in the psychological or physical field, it inextricably results in a variation of the approach, or implies a structural change. The profoundness of this organic change can be the yardstick with which to judge between the arbitrary and ephemeral appearance of stylized motifs and the reality of the process of advancement.

The architectural appearance of the sun control is not an effect in itself—it is the result of several other developments. It is the direct consequence of the glass pane, which in turn was born from structural possibilities. Nevertheless, none of these chain reactions would have evolved at such a rapid pace if the climate of analytical thinking had not allowed the establishment of a hierarchy of specialization. Hence, a separation occurred of the distinct roles played by each element of the wall.

The "wall," in its undifferentiated meaning, is still strongly associated with masonry materials which served for both enclosure and load-bearing, neither used efficiently. With the use of concrete and steel this composite role of the wall becomes articulated. And the tasks of load-carrying and of controlling the environment inside the building become separated. Inevitably, the "skin" was born with the invention of the skeleton.

During this evolutionary step the multi-purpose wall gave way to clear structural members devoted to load-bearing. In connection with it the "curtain" wall performs the role of an environmental filter between indoor and outdoor conditions.

In this role the wall functions as a barrier to certain elements of the surroundings such as rain, snow, and smoke, while acting as a filter to control the entrance or exit of impacts which are beneficial or adverse to the occupants. Among the factors which must be "filtered" are air, heat, cold, wind, light, sounds and odors. There are various ways to control these environmental constituents but it is generally agreed that air, temperature, and sound are best intercepted within the wall itself, while light is easiest to control inside the building shell and heat radiation is most efficiently halted before it reaches the building envelope proper.

Different materials have various capacities to intercept the environmental elements, which are interwoven with each other and exert combined stresses on the human organs. Therefore, any clearcut categorization of the relative importance of these forces becomes somewhat arbitrary. Nevertheless, one could generalize that an opaque wall panel is about ten times better than a glass pane as a barrier against heat impacts. Now if we consider that a shaded glass transmits only about one-third as much heat (an approximate value, depending on latitude, locality and orientation) as an unshaded window surface, it becomes clear that control of radiation impacts is one of the most important tasks the "skin" wall must perform. This has increasing emphasis for the skin's most vulnerable element, the glass curtain.

This proud and lucent element has increased to never-before-known dimensions. The single window, liberated by the structure, instead of remaining a fenestration becomes a window-wall. Man is presented with a psychological sense of freedom, unrestricted views, and a variety of spatial relations. But this transformation has brought some new problems—or rather old problems in sharply enlarged magnitude—of controlling the sun's radiation.

In the spectral composition there are different zones which directly affect humans. These regions can be conveniently categorized into three main divisions according to their wave length. The shortest waves are in the ultra-violet region (erythemal radiation) which have specific importance for their therapeutic value. Since ordinary glass is opaque to these wave lengths, they are, unfortunately, filtered out automatically.

The middle band of the spectrum is the visible (light) range. Here the function of the window is to admit sufficient illumination and yet reduce glare. As mentioned before, this can be regulated most conveniently at the inner side of the building envelope. Because of the relatively easy methods of light control, vulnerability to heat impacts becomes much more important from the point of view of environmental comfort.

Radiation control should, then, focus on the heat waves, which lie mostly in the long-wave infra-red range. Therefore, this publication will treat the whole shading and sun control question from the standpoint of heat regulation. Here the problem asks for diametrically opposite functions from the glass panel; for maximum reception of welcome solar heat in winter, and the exclusion of excessive heat-penetration in summer. Fortunately in this seemingly controversial situation the sun itself offers aid by choosing to travel different paths in the two seasons. This circumstance of solar mechanics invites a degree of automatic seasonal control. The basic architectural means to utilize these advantages are the building shape,[1] and the orientation layout[2] of the structure.

The building skin itself has a decisive role, according to its opaqueness or transmittance, absorption or repellence, of the solar rays.

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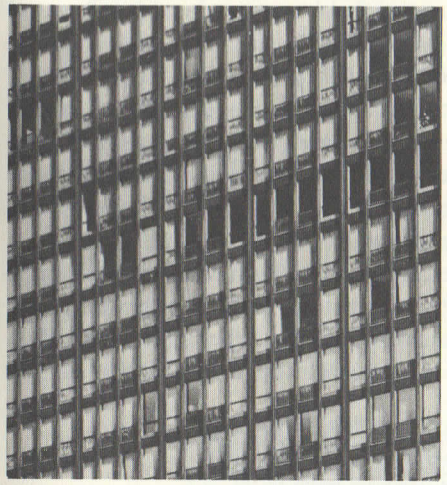
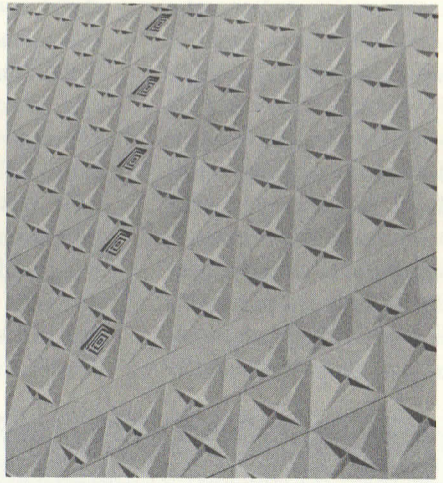
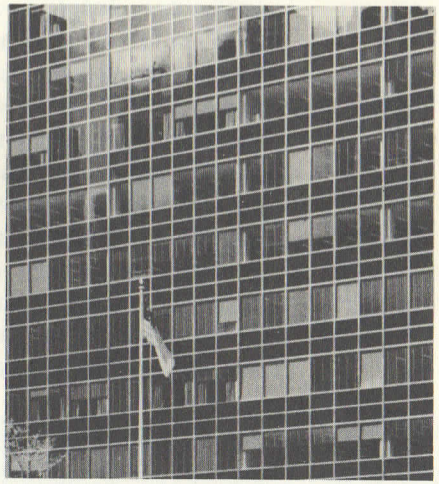


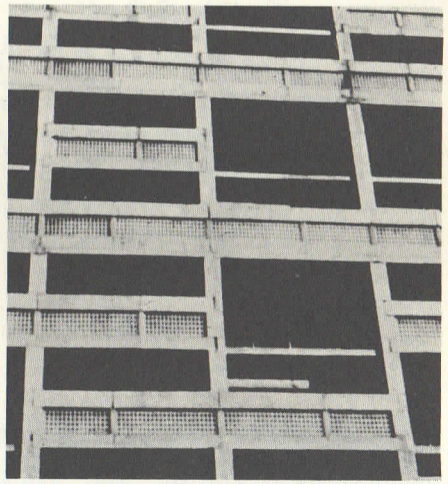
6. Mies Van der Rohe, Lake Shore Apartments, Chicago, Ill.



7. Harrison & Abramovitz, Republic Bank, Dallas, Texas.



8. Skidmore, Owings & Merrill, Lever House, New York.



9. Le Corbusier, Marseille apartments.

Here some examples are shown which compare their relative performances as radiation filters.

The first example (Fig. 6) is a full glass window-wall, which is a lucid expression of the freedom offered and achieved by architectural progress. With its straight approach, appealing as it is, the solution has to absorb all the penalties of the environmental variations, as the bare glass pane offers very little (around 12%) protection. By solar collection on warm clear days the trapped heat rays, in a one-way filter action known as the "greenhouse effect," exaggerate the overheated conditions. This solution can only be regarded as a manifestation of principles rather than a permanent answer to environmental balance.

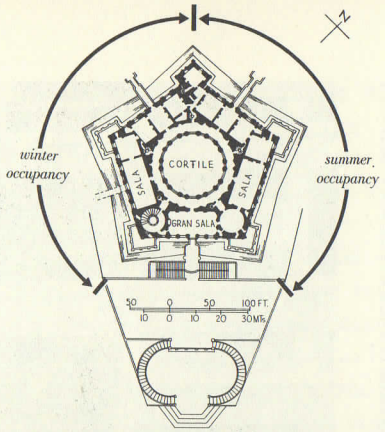
As a diametrically opposite example (Fig. 7) stands the fully opaque curtain wall. In some cases this envelops the building totally, leaving the entirely independent interior free for man-made conditioning. No doubt this solution has its rightful place in specific situations. Some ingenious constructions were developed in this direction, such as the "breathing wall" types. However, a fully engineered atmosphere divorced from nature leaves known psychological deficiencies and most likely has still unexplored physiological drawbacks.

In industrial buildings window panes facing the sun were sometimes painted with bluish tint to keep out the sun's heat. The performance of heat-intercepting glasses is somewhat similar, since the iron content of the glass acts as a selective filter by absorbing a large portion of the infra-red heat rays without much effect on the amount of transmitted light. This permits the use of large window-walls (Fig. 8) with less quantity of heat penetration than that of an ordinary glass curtain. A relatively light-colored heat-absorbing glass intercepts a little over 40% of the radiant energy. This is a considerable aid in summer cooling, but unfortunately represents a similar loss for winter heat gain.

Despite these shortcomings the tinted glass elevations have great current popularity. This is probably due to the fact that a relatively simple solution to the problem of sun-control can be integrated with purely abstract design.

The last example (Fig. 9) illustrates a radiation control solution with shading devices. The method is fundamentally sound. Interception of the energy happens at the right place—before it attacks the building.

In this way the obstructed heat can dissipate into the outside air. Further, if constructed properly, the sunbreaker, being opaque, will intercept all the direct solar radiation and a considerable amount of the diffused. This gives by far the most efficient performance. Here, by shaping the devices according to the changing seasonal sun-path, both summer shading and utilization of winter energies can be performed. To accomplish this—to strive to achieve a relatively constant comfort equilibrium—careful consideration should be given to location, latitude, and orientation, since all these factors play their roles in the formulation of an effective device. In return, the sun-breaker can express a strong spatial character, add new elements to the architectural vocabulary, and phrase a truly regional consciousness.



10. G.B. Vignola, Villa Caprarola, Italy.

The knowledge, or even the approach to the problem of correlating and using the natural elements to please the human needs has a long history.

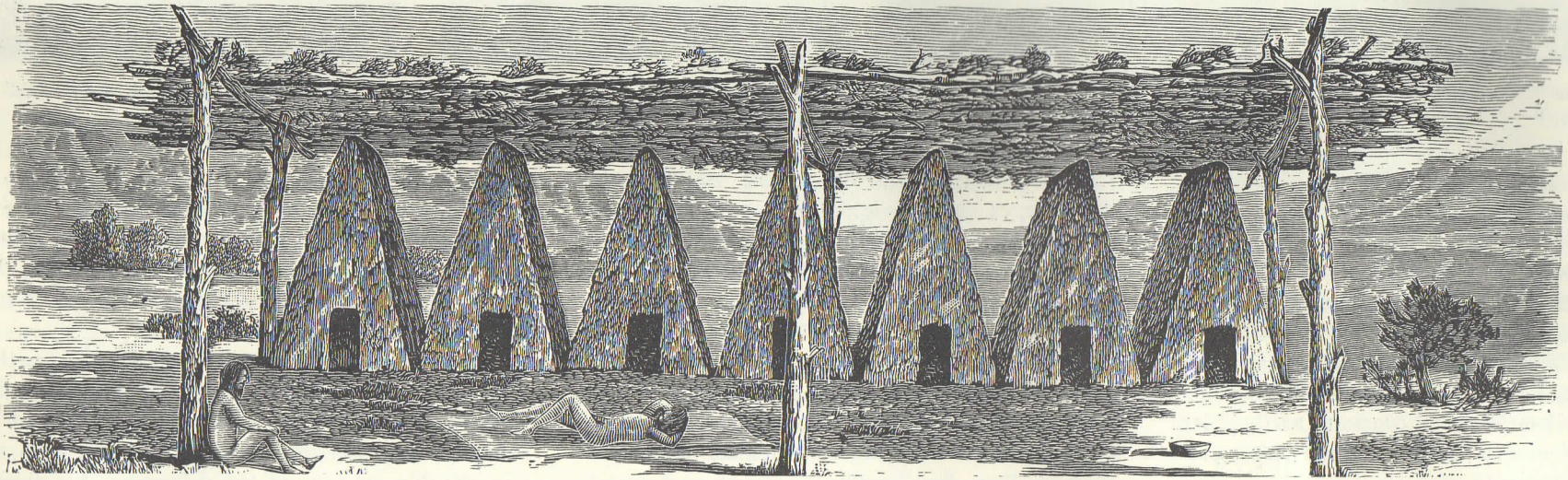
Socrates' sentences about the sun, as quoted in Xenophon's *Memorabilia,* are quite well known: "In houses with a south aspect the sun's rays penetrate into the porticos in winter, but in summer the path of the sun is right over our heads and above the roofs, so that there is shade. If, then, this is the best arrangement, we should build the south side loftier, to get the winter sun, and the north side lower, to keep out the cold winds . . . presumably at once the pleasantest and most beautiful."

In Arabia inspirational solutions and striking forms of expressions exist in the traditional architecture; such are the cantilevered balconies, the delicately formed wood lacework to keep the fierce sun away. In India sometimes whole street facades consist of gracefully carved balcony framework, covering the entire height and length of the exterior with semi-shade.

Sometimes, as at Villa Caprarola (Fig. 10) there were remarkable examples of efforts to use nature itself to help roll back the temperature. Here the axis of the building is also nearly the solar axis, and the structure is symmetrically planned on both sides with a very precise purpose. It was a double dwelling—the southern part was occupied in winter, and the northern part in summer.

At other times the skill of sun control organized the architectural space. A house in Argentina's Tucuman (Figs. 11, 12) can illustrate this. The colonial country house was built in the late eighteenth century by anonymous people following a mixture of Indian and Spanish traditions. The two-story building has only small openings looking East and West. The elevation facing the sun is protected by strong gallery arcades, which act as sun-breakers. Outside the sun cuts sharp contrasts; inside the atmosphere is smooth and cool. Experience and observation brought to life an environmentally balanced unit dedicated to space.

The tradition of the United States is rich in the varied solutions which were applied to re-



13. Indian shelter in Southern California.

lieve the heat of the sun. The Indians often solved their problem with unprecedented originality. In Southern California the Indians of the Yokut Tule Lodge (Fig. 13) not only protected their huts, but in generous, direct manner provided for pleasant living and shaded communal areas.

To the effects of the Gulf Coast's warm humid climate the answer of the early French settlers was the large umbrella roof and the louvered gallery. The delicate iron ornamentation before the walls, which is so characteristic of the South-

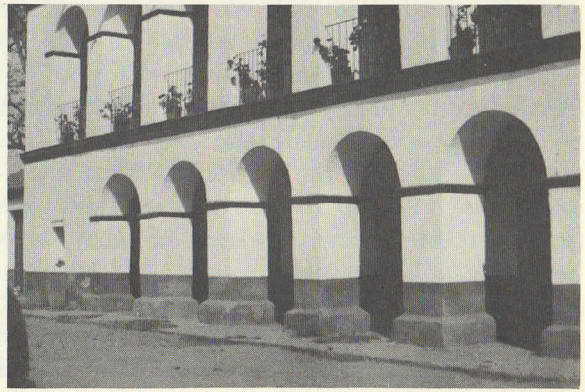
press-wood colonnades keeps the sun away with strength and distinction.

This haphazard touch on some of the historical examples serves to point out the varied knowledge which has been accumulated in the past; insights which in some way have been forgotten in the last decades. Maybe the influence of more northern building methods, the rapidity of migration and remigration, the technical possibility of remedying constructions poorly adapted to climatic environments, all played a part in neglecting valuable experience.

14. Bellechasse plantation, Louisiana.

east with its transparent play of light, served to screen the strength of the sun. In the Southwest, Spanish settlers provided shade with the time-honored patio arrangements, and the streets of pioneer towns were accented with galleries over the sidewalks to keep brilliance in check.

Perhaps one of the most representative types is the plantation house for the warm South. The picture here (Fig. 14) is that of the Bellechasse Plantation erected in the middle of the last century. Galleries run around all four sides of the huge square building and a parasol of cy-



11-12. Tucuman country house in Argentina.

Today, as the view of architectural problems approaches a global scale and as our buildings become more vulnerable to heat exchange, a rediscovery of solar control principles arises and the pursuit of solutions becomes an important matter. The importance of this new element is shown even by the fact that more than one architect feels that he was the originator of its conscious use as a means of architectural expression. Without much doubt, Corbusier's crystalline principles and forceful phrasing lead the idea to become indisputably architecture.

Let us follow the development of the sun-breaker through the sketches and wording of Corbusier as he describes it in connection with his work:

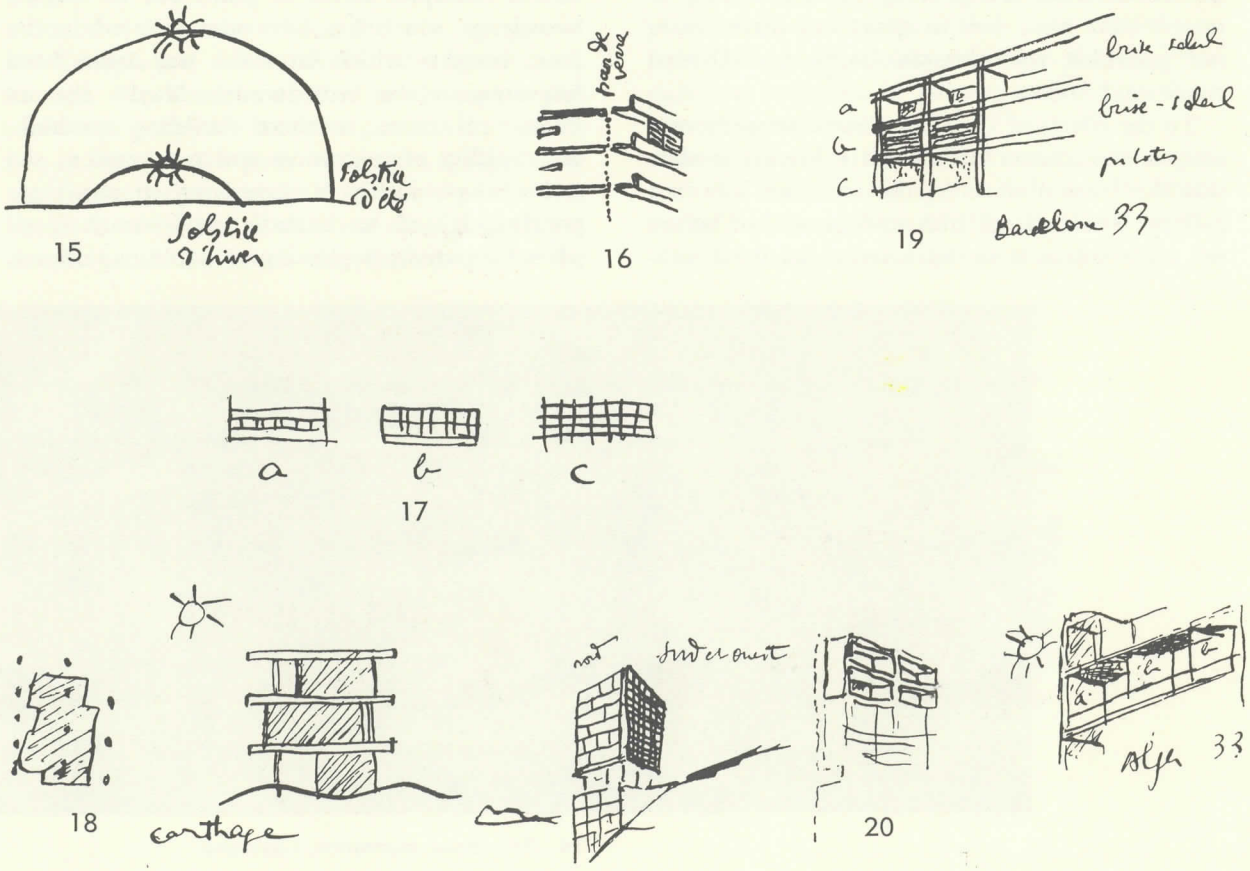
". . . one could say that the history of windows is the same as that of architecture or, at least, this is the trait which is the most characteristic in the history of architecture.

". . . today as we possess steel and reinforced concrete . . . nothing these days prevents us from opening toward the solar rays, not a mere fraction, but 100 per cent of a facade. . . .

"This new freedom gave enormous possibilities for fantasy—but it is evident that it posed new problems at the same time. . . .

". . . the play of the seasons brings its adverse and beneficial effects—at the winter solstice the sun lies low at the horizon and its rays are welcome in the interiors of our habitation where they kindle our moral and physical self. (Fig. 15) The spring and fall mid-seasons greatly gratify themselves by offering sunlight which is sweet to all creatures. During the dog-days of the summer solstice, with its intolerable temperatures, the sun, our customary friend, becomes an implacable enemy; the need in those hours for shade is imperative.

"It becomes necessary to stop up the windows, to 'diaphragm' the glass pane. What aids are available to achieve this purpose? There may be

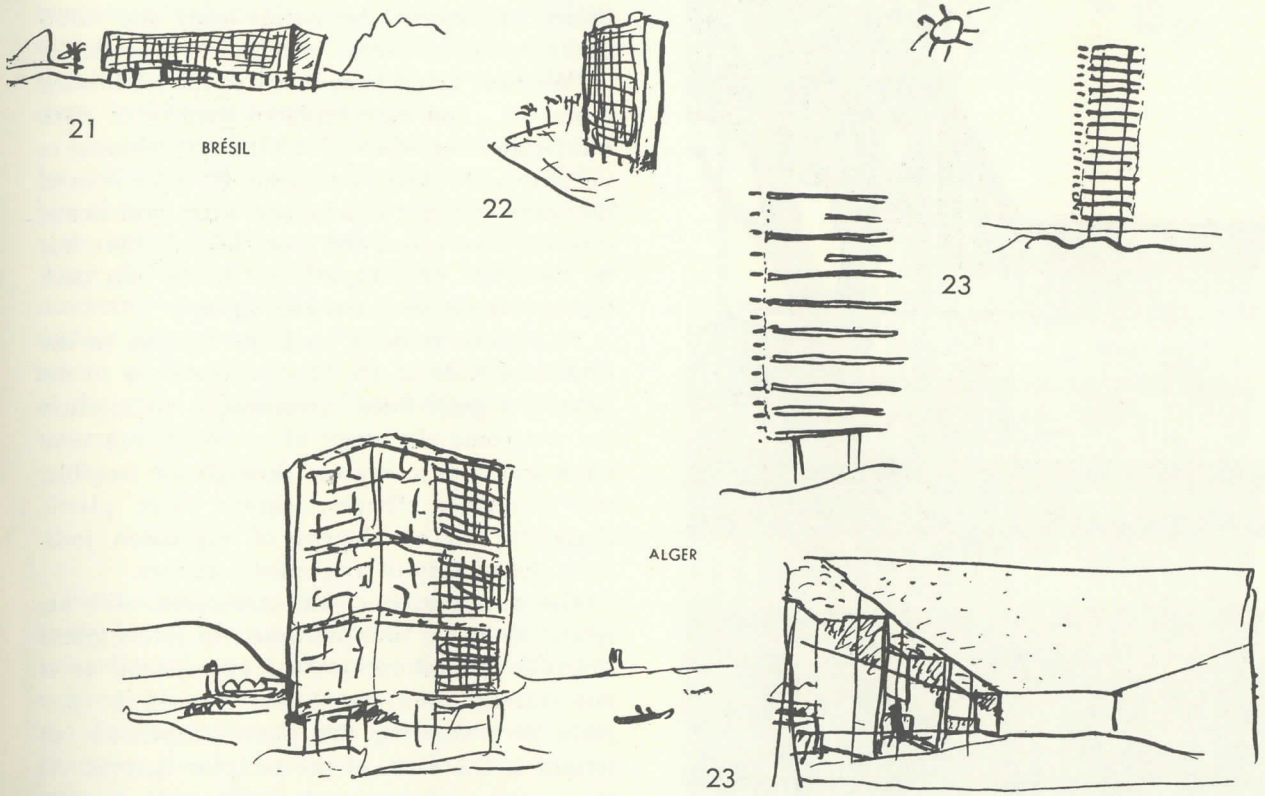


15-23. Corbusier.

superimposed curtain filters of loose and tight texture, shutters of various nature applied inside or outside, and screens of new design which can be developed to work in mutual conjunction with the glass pane. . . ."

(Fig. 16) Solutions of the different fenestration methods illustrate the conquest of the glass panel in Corbusier's early works from 1921 to 1928; the simple horizontal window arrangement (a), the double row (b), and the final stage of the full glass panel (c).

(Fig. 17) In Geneva at the apartment house "Clarté" an early instinctive approach toward the sun-breaker is revealed. Here the broad elongation of the floors over the glass surface created the first solution which satisfactorily ad-



mitted the low winter sun and intercepted the high summer sun.

(Fig. 18) In 1928 a house was planned in Carthage. Here the structure of the house is completely independent of the form of the habitation proper, which retreats for shade protection, giving the structure the added role of a sun-breaker.

(Fig. 19) In 1933 the approach to rural dwellings in Barcelona shows the doctrine more eloquently. Here the upper story (a) is protected by deep loggias. The middle story (b) achieves its defense by horizontally-pivoted concrete shutters, and the ground floor is open to create a shaded area (c).

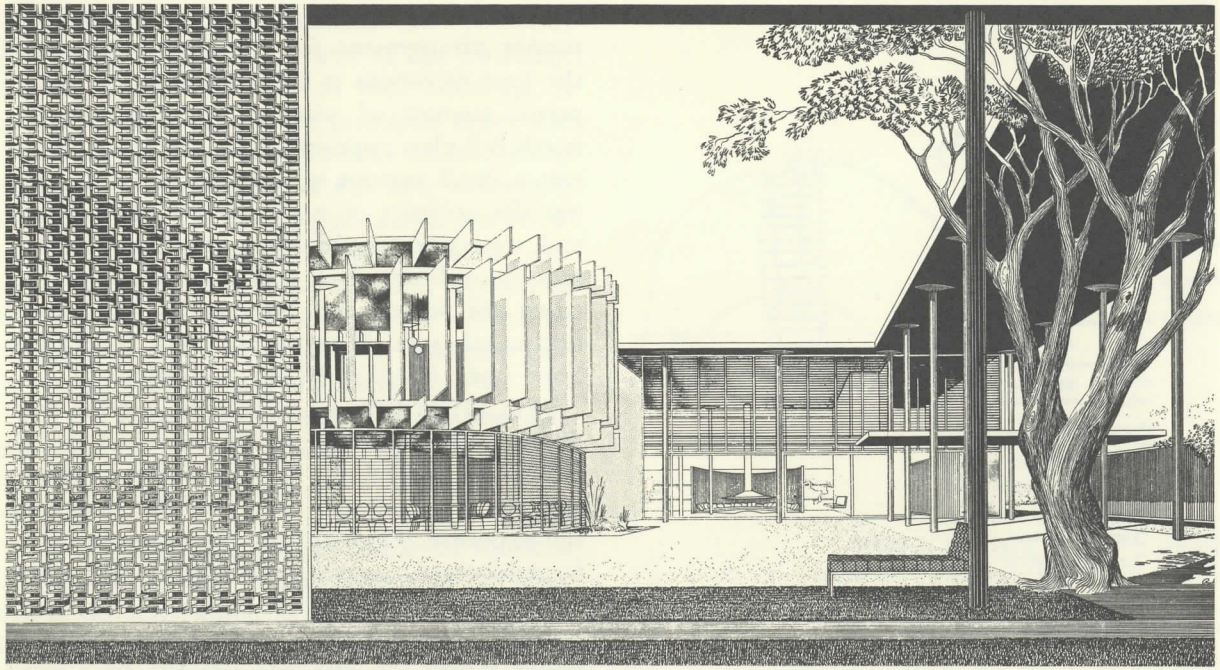
(Fig. 20). The apartment house in Algiers of 1933 pushes the principles further. To achieve proper arrangement for solar control each of the four elevations is balanced with the appropriate amount of window openings. On the north full glass appears on the elevation. At the east a small amount of opening is placed without the necessity of sun control. On the south and west sides sun-breakers are installed. The most punishing effect occurs at the west side when the setting sun projects its low, nearly horizontal, rays. Here vertical fins (a), or oblique ones (b) provide sun protection.

(Fig. 21) In 1936, when the first sketches were drawn for the Ministry of Education and Health in Rio de Janeiro, the problem arose to choose between the desirable view and the punishing sun exposure. The resulting elevation, protected by sun-breakers, gave a courageous answer in free design.

(Fig. 22) It was in this place that the Corbusier theory was put into practice on a large scale for the first time. The impetus of this planning has been interpreted with brilliance since then, and the "quebra sol" became almost the trademark of Brazilian architecture.

(Fig. 23) In 1938, in a plan for Algeria, the arrangement of solar control and construction is organically coupled. The *brise-soleil* unites with a clear system of construction as an "incontestable element of architecture." The elevation is molded into unity through the dramatic use of this new element. ". . . the cadence, proportioned all to the human scale, allows varied, authorized fantasy, . . . is assured against all chances: there is harmony in all its parts. And no estrangement of our sensibilities is possible."

Corbusier's words were drawn both from intellectual and emotional channels. His approach of logic stems from practical observation, his expression lies in the realm of feelings.



24. Paul Rudolph, Fraternity House for University of Miami.

25. Harry Bertoia, Metal screen wall.

Today the practical and direct expression of rational necessities no longer gives complete satisfaction. The last three decades of functional approach won this battle, but the war continues, to conquer the lyrical heart and fulfill all its emotional needs. As Belluschi expressed it —"We have taken away many of the established forms. . . . and have replaced them with stark utilitarian ones, which give little nourishment to the senses. We have taken away from the man of the street all the stereotyped little ornaments, cornices, cartouches, and green fake shutters, but we have not been capable of giving him back the equivalent in emotional value."[3]

This drive to bring back the interest in the emotional scale of the human, the sense of delight, is a great force. Accordingly, architecture has overcome the stage of orthodox functionalism and tries to express, through the tangible, the intangible. Shapes acquire more plastic character. An enrichment of expression indicates the vitality of awakened impulses.

The composition of the sun-screen, with its spatial character and multitude of forms, offers a fertile ground for sensual experiment. It is not entirely coincidental that one of the pictures here showing the plastic expression of screens is the work of the sculptor Bertoia. At this point sculpture and architecture parallel each other. And here the fact in itself is important that a field, where usually the sensory experiences are dominant, leans toward formulations which are of architectural derivation.

The effect of playfulness warms the heart and pleases the eye, for there is place for spontaneous action, for an unquestioned quality of delight. This lively attitude can be a proof of the vitality of contemporary architecture, the sign that the principles—the more abstract groundwork—have been thoroughly accepted and have matured to the point where the luxury of emotional variation can flourish.

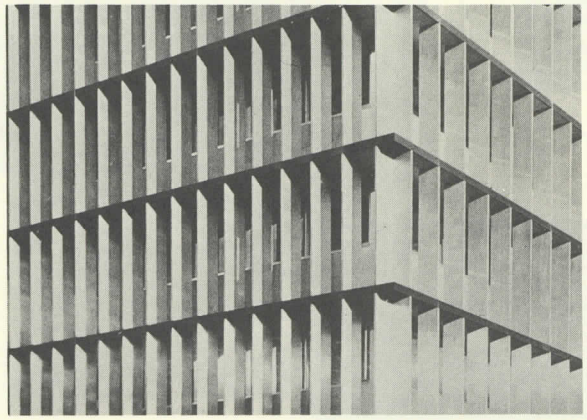
This freedom of the emotional imagination should, at the same time, be used with caution. Owing to the path of the sun, which constantly changes both its altitude and bearing, shading devices should vary according to their orientation. The devices should change types or dimensions in differently oriented walls.

The new vocabulary of forms is not an excuse for petty embellishments responding to whim, but should conserve the principles of the very same order which gave birth to it. There is a sharp difference between playful variations of simmered convictions, and rootless, capricious, surface ornamentation. The advancement in a school of thought should be a continuous flow of the main stream, and hence subjected to the same principles.

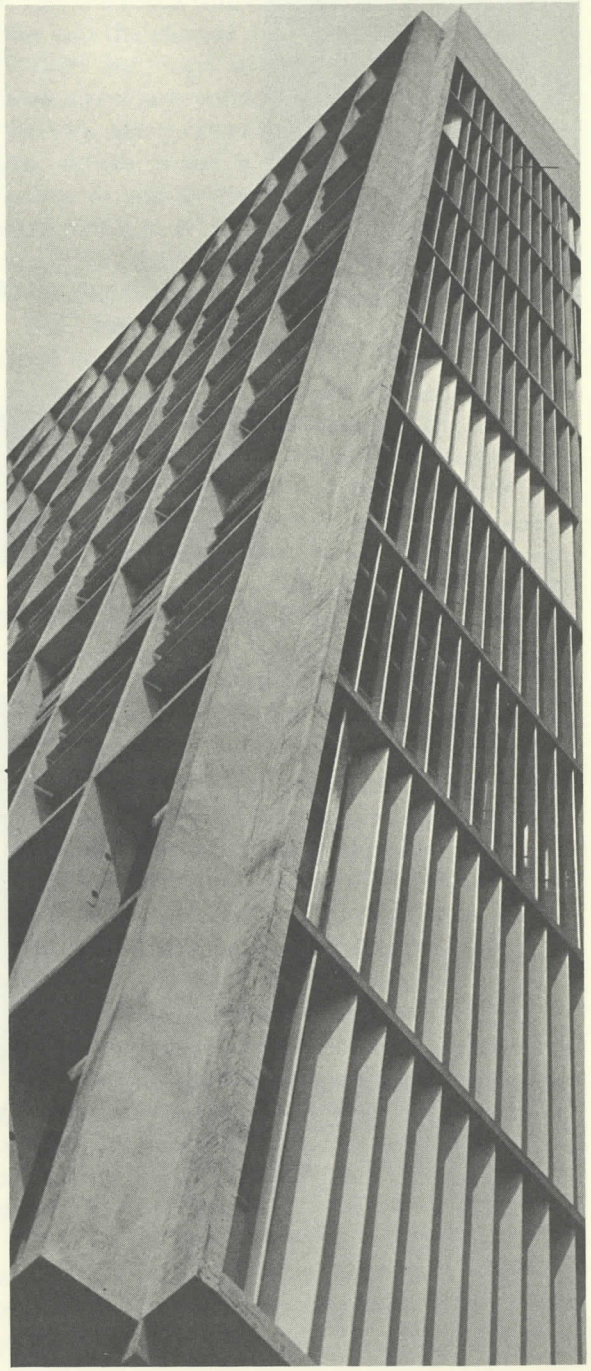
Nature with its infinite variations is a superb example of how a multitude of organisms—subordinated to a complicated hierarchy of rules—produces its abundant creations without the slightest feeling of restriction. Here the ever-changing possibilities evoke, within the boundaries of order, their new species.

The intellectual discipline which gave rise to the contemporary movement with its clear analytical statements should supply the *leitmotiv* in the adventure of feeling. As Goethe phrased it, "Freedom can be achieved only through Order."

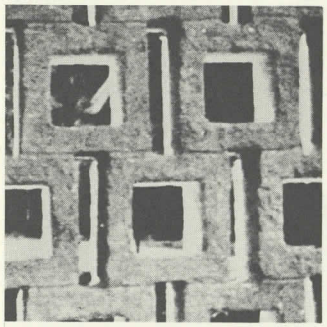
Intuition and fantasy—those admirable companions of art—can really help us in achieving the essential goal if they are instinctive disciples of clear thinking. Subjective interpretations and ad libitum emotional solutions can be valid only after the fulfillment of intellectual obligations, for within the balance of knowing and feeling a work can truly fulfill its creative role.



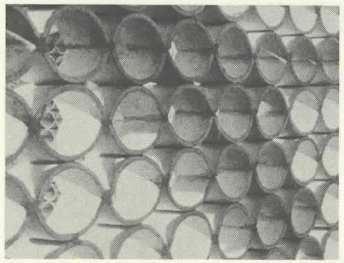
27. A building which does not take orientation into consideration. . .



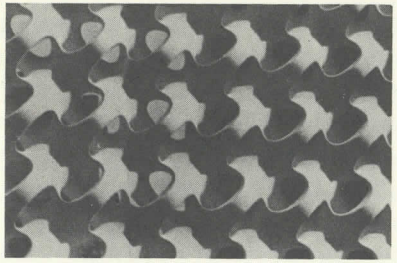
26. a building which knows that differently oriented walls need different kinds of shading devices.



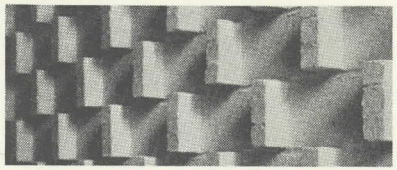
28. J.L. Couter, Bizerte, Tunisia.



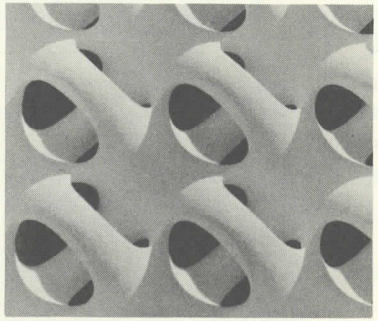
30. Anshen & Allen, Taxco, Mexico.

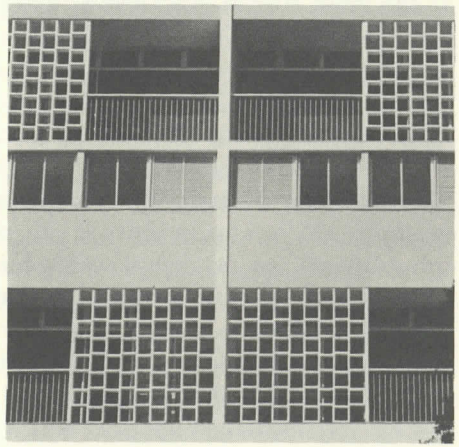


33-34. E. Hauer, sculptor, Vienna, Austria.

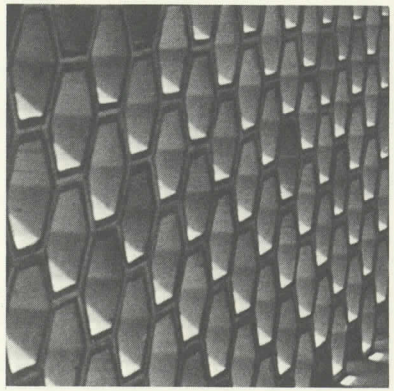


31. M. Breuer, Bronxville, N.Y.

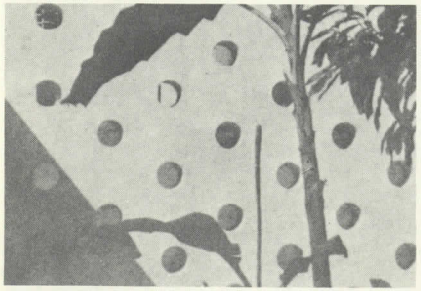




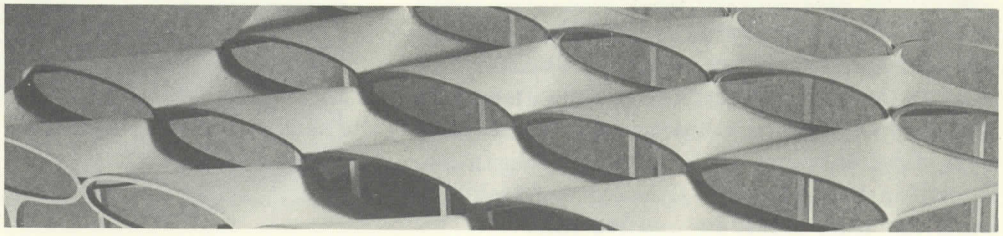
36. A. Reidy, Rio de Janeiro.



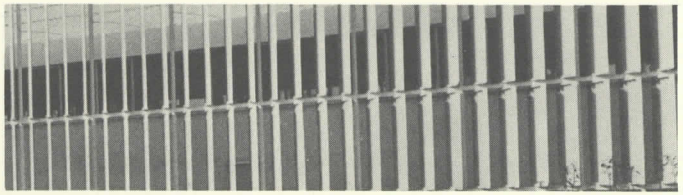
32. Open tile wall.



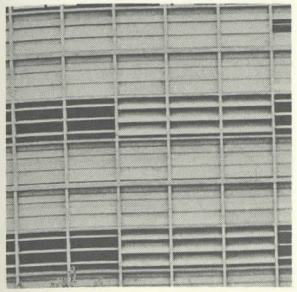
29. A.E. Reidy, Rio de Janeiro.



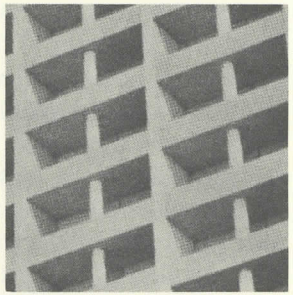
35. H. Caminos, Tucuman, Argentina.



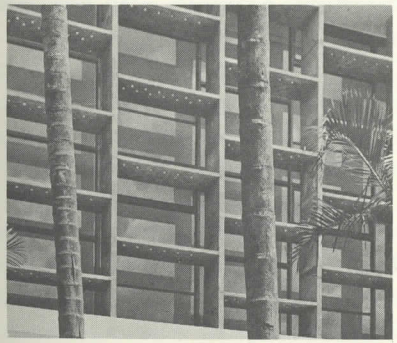
39. M.M.M. Roberto, Rio de Janeiro.



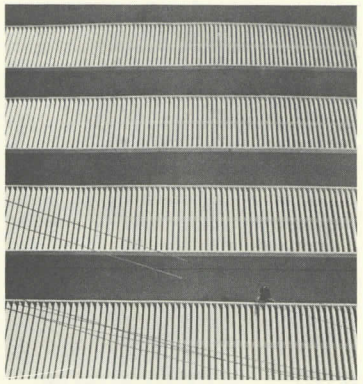
37. A. Raymond, Pondichery.



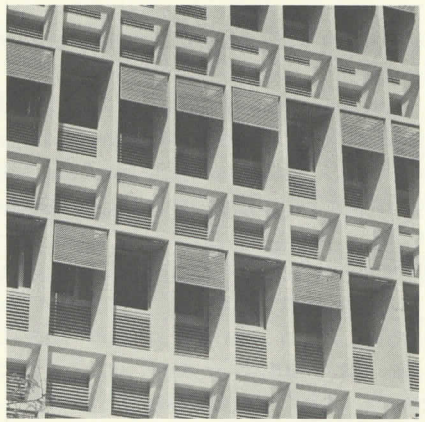
40. Le Corbusier, Algiers



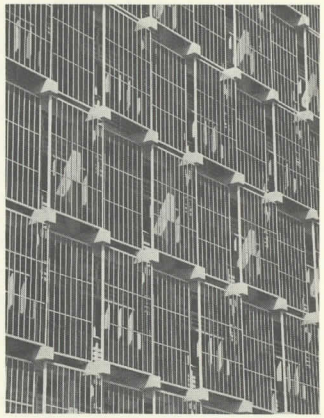
41. O. Niemeyer, San Paolo, Brazil



38. Lucchichenti & Monaco, Tarente, Italy.



42. M.M.M. Roberto, Rio de Janeiro.



43. P.A. Ribero, Bahia, Brazil.

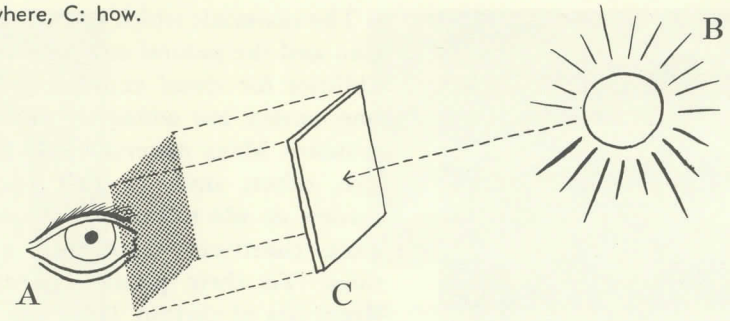
The materials which provide a screen between man and the natural environment offer rich possibilities for visual expression. With them new components are added to the architectural vocabulary. Many materials only elaborate the surface, others invite a rich play of light and shadow or add to the spatial composition, while some constitute their own architectural entities. To their plastic appearance they add visual ties of rhythm, light, color and texture.

The elements shown are independent of direct scale, leaving only the geometrical relationships to be their masters. As compositions, the screens offer large variations. This diversity is not incidental. Their character is representative of positive functions, as the dominant patterns are basically designs of their specific uses.

Some patterns let the air movement through (Fig. 28), and provide shade with more (Fig. 29) or less (Fig. 30) privacy. Some use the wind to cool the wall and defend it by half shade (Fig. 31). Patterns might be geometrical (Fig. 32) or use the fluid play of the *claire-obscure* of the light (Figs. 33, 34). This can be horizontal (Fig. 35) by ingenious utilization of spatial constructions. The shading elements of elevations in combination with deep balconies (Fig. 36) provides rich texture. Horizontal devices can be closed in character (Fig. 37), but nearly similar shading effect can be reached with butterfly-light balconies (Fig. 38). Some orientations call for vertical shading members with movable (Fig. 39) or with fixed fins (Fig. 40) which dominate the appearance of the elevation. In certain locations the eggcrate sun-breaker provides the needed coolness by screening before the glass (Fig. 41), or by creating with twofold depth (Figs. 42, 43) the elevation itself.

The motifs vary, but are subordinate to the sun, whose strength and angles, according to orientation and location, prescribe the regional patterns.

44. A: when, B: where, C: how.



II. THE METHOD: WHEN, WHERE, HOW

IT IS generally agreed that the principle of thermal sun-control is to let the sun's energy into the building during the winter and to intercept it in the summer. This simplified principle gained wide acceptance in architectural practice, prescribing overhangs according to the winter and summer solstice angles.

This method, basically valid with rule-of-thumb effectiveness, was born as a response to the solar house's need of summer protection; it provided applicable solutions only to the south side of the building, leaving the other sides to the unguarded discretion of the designer. Further, the provision for full shade according to the solstice date, June 21, while the warmest days usually occur around the end of July or the beginning of August leaves some doubt, even in the cooler temperate areas, as to the validity of this method. And in tropical zones, where undoubtedly longer periods require full shade protection, the shortcomings are more evident.

With this in mind, the requirements of solar control should be rephrased so as to have the sun strike the walls and allow the desirable heat energy into the building at all times when the weather is cool; conversely, let us place the building proper in shade at all times when it is hot. On this principle a balanced solar-heat control can be achieved.

For this, the first requirement is to clarify what constitutes "cool," and conversely, what can be called "hot." The yardstick to these relative measures is our senses, or rather our physiological reactions.

For any given locality the climatic conditions, mainly the temperature, give an index for outlining cool and warm periods which can be designated as the "underheated" and "overheated" periods. The "overheated" period is the one when shading is needed.

With these divisions we are in the position to know *"when"* the sun should be intercepted. To know *"where"* the specific positions of the sun are during the overheated periods, the sunpath diagram can give a positive answer based on the sun's angles. The determination of the *"when"* and *"where"* gives us the data necessary to answer the question *"how."*

The principle used here to calculate for a shading device can be described as the one which maintains the thermal balance of radiation and shading according to the under- or over-heated periods.

The method is simple, but some of the technical details may seem strenuous. Of the four main sections of this publication, the second part describes technical background considerations such as Bioclimatic Evaluation, Sun-Mechanics, Model Measurements, Sun-path Diagrams, Obstructions, Solar Energy, Transmissions, and Economy. These studies, however important to clarify the approach and to understand the limitations of the method, are not a necessity for those who are interested merely in the application. In looking for direct architectural applicability one may skip this technical part and begin at the following section on Practical Application (Part 3). As the evaluations can be interpreted in many ways, giving freedom for manifold expression, the last section (Part 4) contains architectural examples with analyses of their performance.

The aim of this publication is to clarify the method of solar control. The approach is based on the belief that architectural expressions should grow from the ground of objective analyses—and that the realm of feelings, the emotional content, should draw its synthesis beyond the technical level. Then can architecture—by fulfilling its dual role of satisfying emotional and physical needs—develop its true expression.

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PART 2 TECHNICAL CONSIDERATIONS

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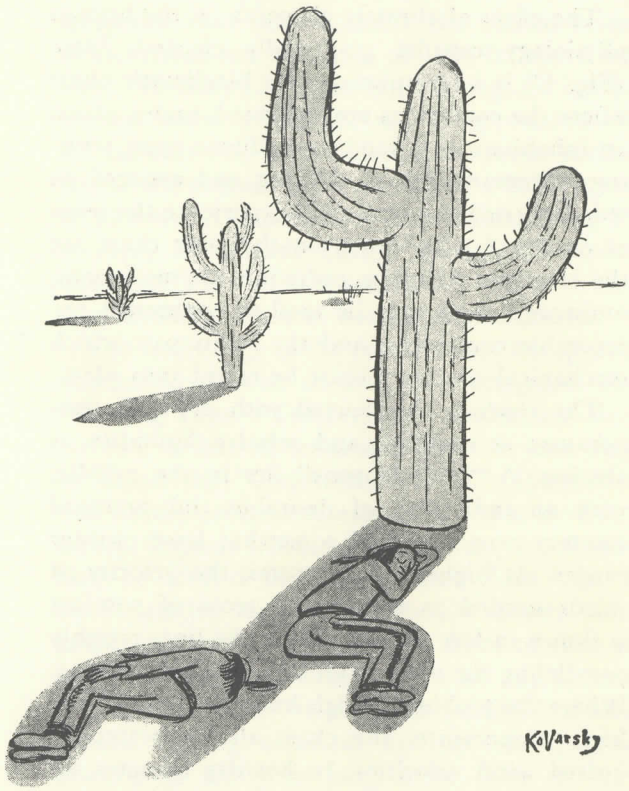
III. BIOCLIMATIC CONSIDERATIONS

THE world and its life are literally submerged in a fluid sea of atmosphere wherein the thermal characteristics have a most important effect on the process of living. All creatures are subjected to the extremes of heat and coolness, but most animals are much better equipped than man to escape such impacts or counteract them biologically.

As cold arrives the mink grows a new fur coat, birds fly south and the bear hibernates to reduce its metabolism through slumber. To cool his blood in hot weather, the elephant moves his honeycombed ears. The bat can survive a change in its own body temperature of 60°.

Changing climatic conditions also invite associated patterns of behavior, as has been studied in birds.[4] The pheasant abandons its usual shape to become fluffy at 4°C and under −2°C will stand only on one leg. This bird enjoys sunshine until the temperature rises to 85°F, but after that seeks shade and at 88°F begins to pant.

Man was not as fortunate at the Genesis. He has very limited natural controls with which to encounter variations of the unfriendly climate, where he has to maintain his body temperature close to 98.6°F—or perish. In this struggle of adaptation the energy of the sun plays a major role. Its rays are more than welcome in cool conditions, but it becomes essential to escape from them on hot days. Such is the case of the little boy in Hong Kong shown opposite, whose only concern is shade to cope with his immediate environment.

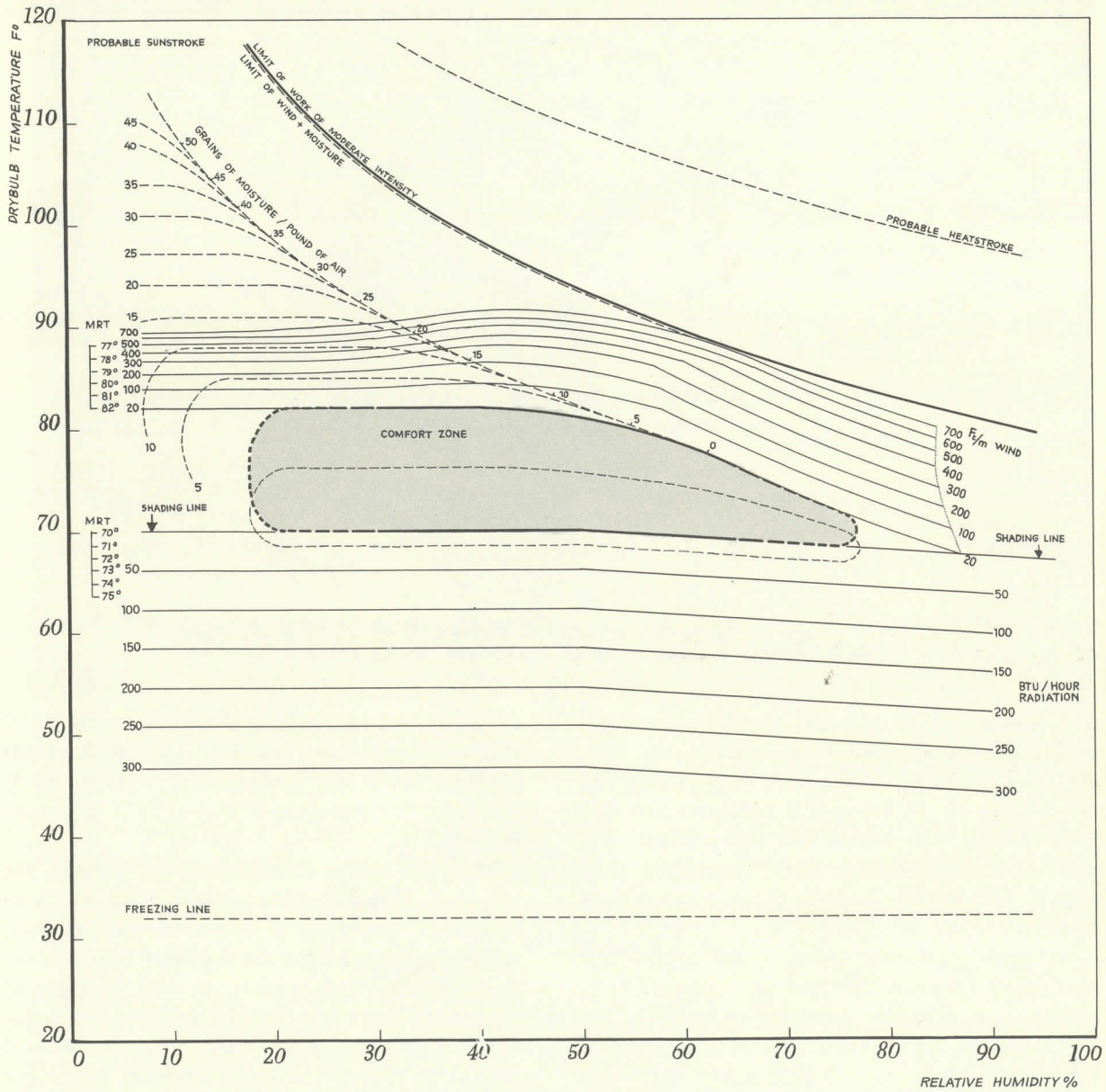


46. Drawing by Kovarsky, © 1948 The New Yorker Magazine, Inc.

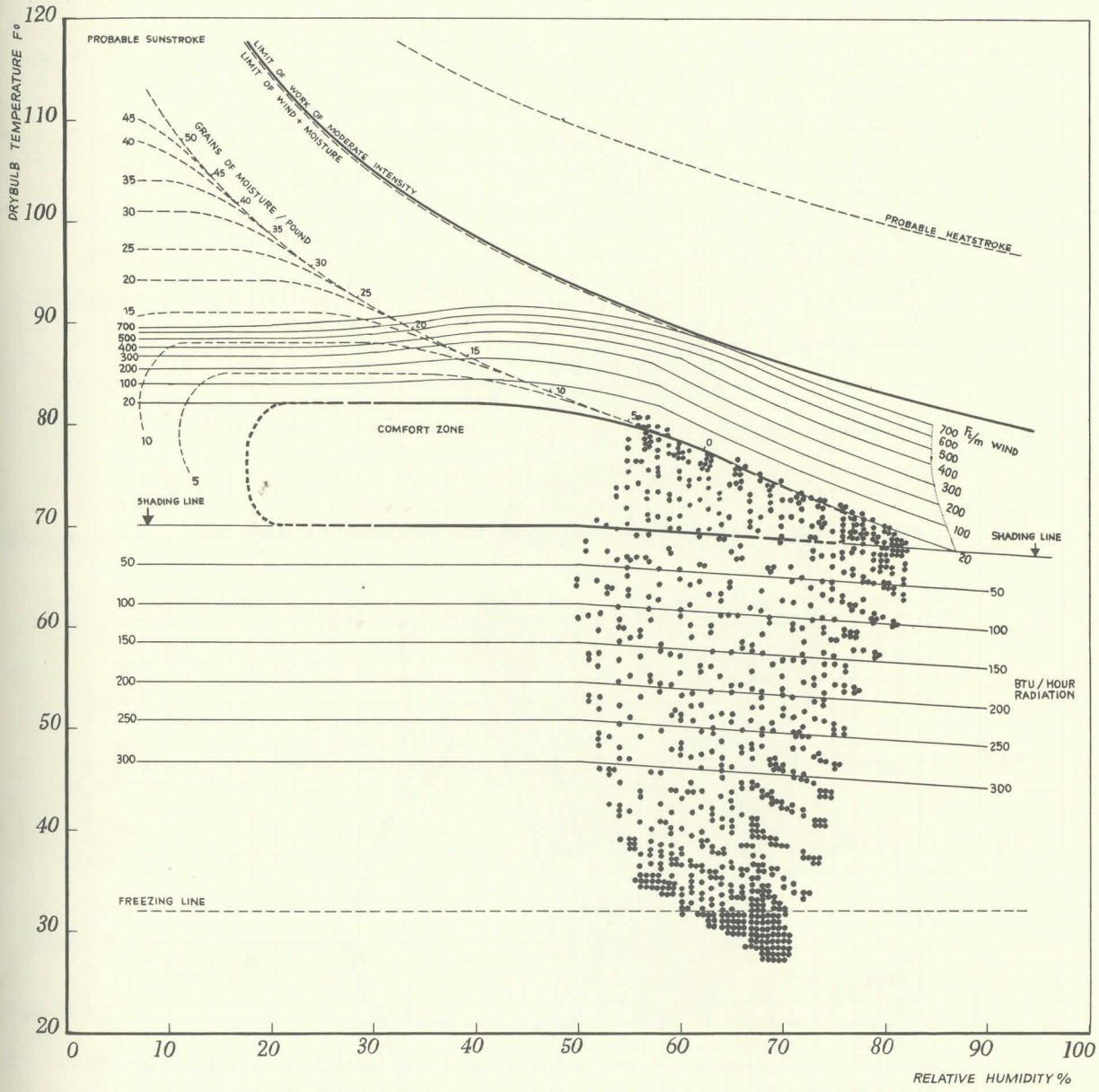
The effect of climatic elements on the human physiology can be graphically charted. Here (Fig. 47) is a formulation of a bioclimatic chart where the conditions are indicated, under which an inhabitant of a moderate climate zone, wearing customary indoor clothing and engaged in sedentary or light work, will experience the sense of comfort.[5] Also shown on the same chart are the elements (shading, radiation, air movement, moisture) which may be used to counteract unfavorable conditions, and the limits past which mechanical measures must be called into play.

The chart is constructed with dry-bulb temperature as ordinate and relative humidity as abscissa. A "comfort zone" lies in the middle, with an indication of desirable and practical summer ranges and of somewhat lower winter ranges. At higher temperatures, the velocity of winds needed to restore the sense of comfort is shown in feet per minute on the lines roughly paralleling the upper limits of the comfort zone. Where the problem is high humidity rather than high temperature, the chart also indicates required wind velocities. In hot dry climates air movements of considerable velocity have little effect, and evaporative cooling may be of use in restoring a feeling of comfort if latent heat of vaporization is supplied by the air. The chart indicates amounts of moisture to be added in grains per pound of air. The lower edge of the comfort zone is the line above which shading is needed and below which solar radiation should be utilized. The limited degree to which variations in mean radiant temperature may restore feelings of comfort are indicated along the left side, and on the right a measure is given of the solar radiation per hour needed to offset heat losses of the human body in the open at lower temperatures.

The chart has its limitations. Age, sex, habits, all play a part in individual comfort, though these factors have had to be correlated into a sin-



47. Bioclimatic Chart, for U.S. moderate zone inhabitants.



48. The average yearly conditions of the New York-New Jersey area, where each point represents hourly data over ten day periods throughout the year.

gle index. Its application is valid directly to the temperate zone inhabitants of the United States at elevations not in excess of 1000 ft. above sea level. To calculate other climate regions in the United States which are not at approximately 40° latitude one should elevate the lower perimeter of the summer comfort line by a half degree of Effective Temperature (approximately ¾°F) at every 5° latitude change toward the lower latitudes. This adjustment is the result of human acclimatization to warmer environments.

The lower edge of the comfort zone has special importance in solar control, as it designates the "Shading Line." Temperatures under this line are cool to human sensations and this area may be called the "Underheated Zone." Above the line lie the areas of comfort and warm environmental impacts which, since they require shade, may be termed the "Overheated Zone." In a more detailed manner one should classify "underheated period," where some form of heat is required—"comfort zone," where no adjustment is necessary—and "overheated period," where certain cooling measures are needed. But as shading is really nothing more than an expression of the absence of radiation, the above categorization seems justified for its practical simplicity.

Through the use of the bioclimatic chart one may plot climate conditions for any time and location to see whether they are within the comfort zone. If they are not, one is given an indication of the measures which may be taken to bring about a sense of comfort.

Plotting of combined temperature and relative humidity data on the chart at regular intervals will show general characteristics of the region. With such a graphical "diagnosis of the region" the relative importance of the various climatic elements—such as the need for radiation, or shade—can be evaluated, (see Fig. 48).

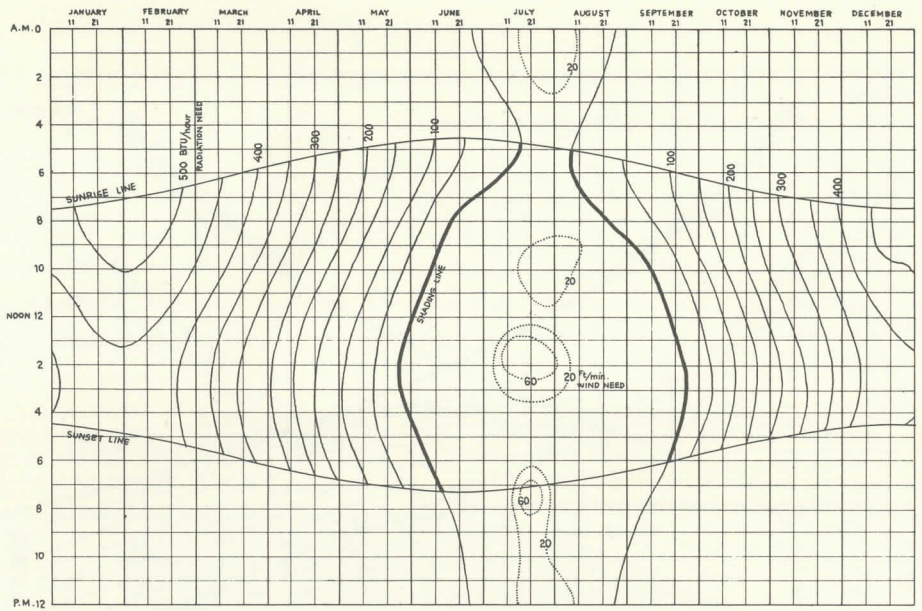
The bioclimatic analysis of a specific region can be translated to a yearly chart. The chart (Fig. 49) indicates the information from the New York-New Jersey area transformed into a time table form, showing average data primarily during daytime hours. The chart indicates for the colder months the amount of radiation needed in British thermal units per hour. This "underheated period" extends over the greater part of the year in the region in question. During the summer months the shading lines indicate a period when shading is required; during the very hottest period, there are certain times during which additional air movement is needed to give a sense of comfort.

Here, in the approach to sun control, the most important index is the "overheated period" which lies between the heavier shading lines.

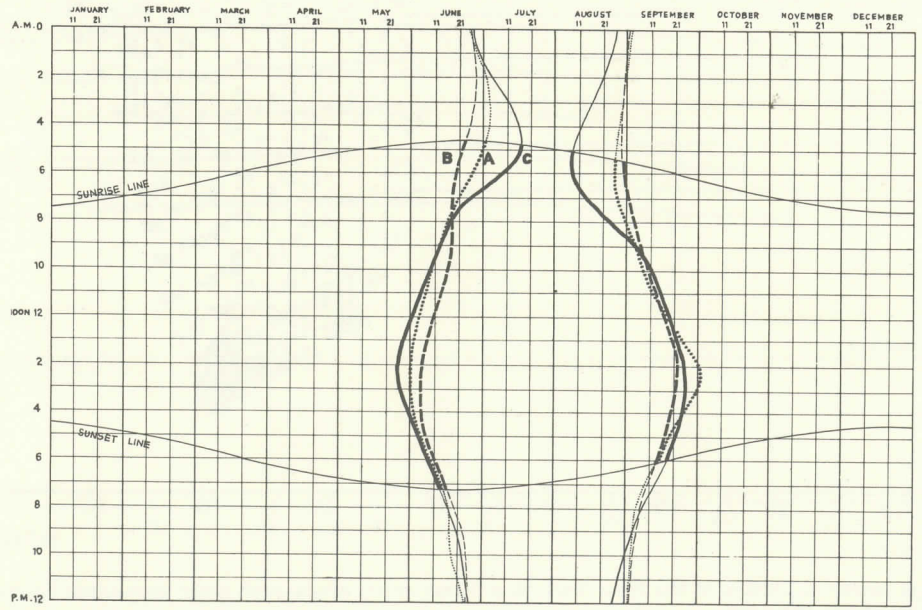
As the evaluated data is the direct result of the outdoor climatic conditions, and as the aim of the solar control is to improve the conditions indoors—it seems appropriate here to clarify the thermal relationship between the two environments.

The cyclic variations of outdoor thermal conditions tend to produce related cyclic variations inside the structure. These are deferred in time and reduced in amplitude, depending upon the character of the structure.

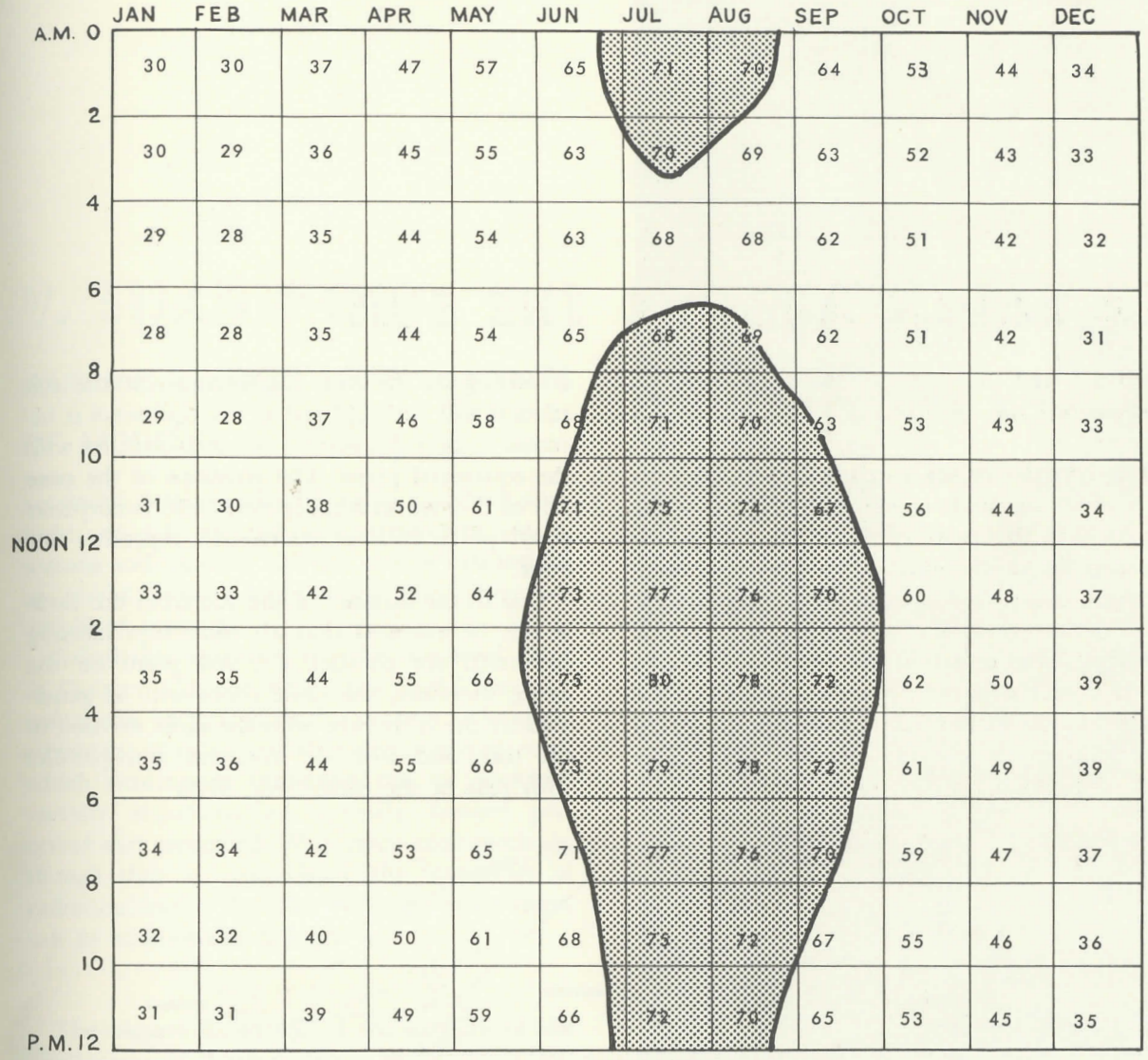
According to observations the indoor temperature can be related to the outdoor shade temperature through the function of the "effective weight" of the structure.[6] With the above method two structures were calculated as comparative examples. "Effective weights" were figured for a light frame, and for a brick and tile construction, and the thermal behavior of the two types were graphed under average daily temperature conditions. The indoor temperatures thus obtained were then evaluated on the basis of the bioclimatic chart to determine the overheated period within the structure.



49. The analysis of the New York-New Jersey area translated to a yearly chart.



50. Comparison of the outdoor overheated period "C," with the overheated periods within the frame house "A," and within the brick house "B," by plotting them together, adjusted to set aside time lag.



51. Shading analysis of the New York-New Jersey area with the use of temperature data only.

The time lag is a function of the structure only, and independent of the temperature variations; this means that heat impulse, or interception of radiation on the outside will directly affect inside temperature after the appropriate time lag. This consideration gives the freedom to compare these effects (Fig. 50). The graph speaks for itself. The negligible differences between the three curves lead to the conclusion that, for all practical purposes, the outdoor overheated period is a safe approximation for shading calculations from light to moderately heavy constructions.

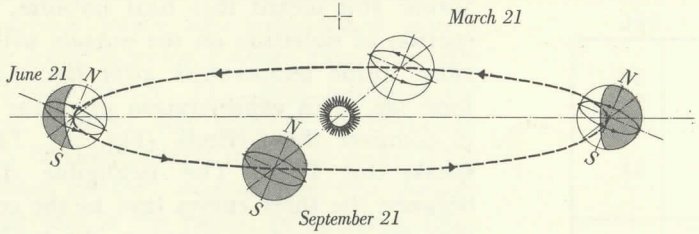
For detailed climatic analysis of a region the bioclimatic evaluation is desirable; however, for shading calculations, a simplified method can be used.

As the humidity has little impact on the shading line, and thus occurs only at the higher relative humidity ranges, the effect can be neglected. Doing so, the convenient maxim can be adopted in the temperate region that every condition which is below 70°F belongs to the "underheated" period, while temperatures above it should be categorized as an "overheated" condition.

Fig. 51 illustrates the shading analyses of the New York-New Jersey area with the use of temperature data only. The result in comparison to the bioclimatic evaluation differs only in the early morning period on account of the high humidities at that time. Otherwise at all daytime hours the analyses are exactly the same. The dark area designates the overheated period.

Other geographical locations, naturally, have other overheated periods, as this depends on the shading line of the region and on their specific climatic conditions. But the rule remains everywhere the same: during underheated times the sun should strike and permeate the structure, while at overheated times the building should lie in shade.

52. The path of the earth around the sun.



IV. THE MOTION OF THE EARTH AROUND THE SUN

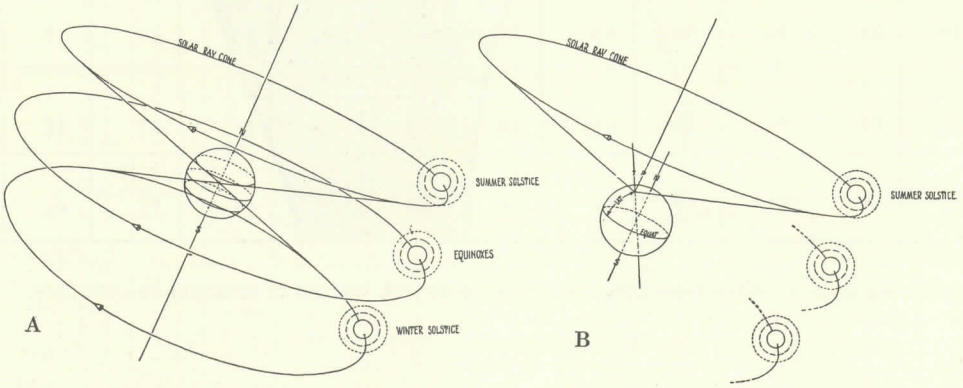
BEFORE entering into the description of shading measurements and of sun-path diagrams, it is pertinent to give a short summary of the astronomical relations of the sun and the earth.

The earth travels in an almost circular orbit around the sun, as indicated diagrammatically in Fig. 52. It is rotating about its own axis (N,S) at the rate of one revolution per day, and is moving at the same time in the closed path in a year. Its axis (N,S) is not perpendicular to the plane of its orbit (called ecliptic) but is inclined at an angle of 23° 27′ (practically taken at 23½°), so that when it is at the date point around Dec. 21 and the north pole is inclined directly away from the sun, the latter appears to be at declination −23½°. A quarter of a year later, when the earth reaches the date-point around March 21, the sun's declination will be zero, and three months later still, when the earth passes through the date point on June 21, it will be +23½°, while on the date-point about Sept. 21 it will again be zero.

The direction of the sun-rays in relation to the earth varies on different dates. For the northern hemisphere the dates which have extreme declinations, are called the winter solstice, around December 21, the vernal and autumnal equinoxes around March 21 and Sept. 21 respectively, and the summer solstice on June 21. Declinations on other dates are tabulated on page 31.

The rotation of the earth on its axis occurs once every twenty-four hours. This movement can be visualized more easily by describing how this appears to an observer on the earth, neglecting the earth's elliptical path. The sun appears to revolve around the earth once in this period. To the centre of the earth, the rays of the sun will describe an envelope of a cone which has the earth's axis as its own axis. This cone is called the solar ray cone (Fig. 53A). The slant of the solar ray cone varies during the year according to the sun's declination: at the solstices it will be 23½° and at the equinoxes it becomes 0° or a flat surface which is parallel with the equatorial plane. The envelope of the cone can be divided with radial lines into twenty-four equal parts, each of which will represent one hour.

Due to the distance of the sun from the earth it can be assumed that all solar rays meeting the earth are parallel. On any point on the earth, therefore, the same cones will be generated by the solar rays, with the same division of the time and with the common axis parallel with that of the earth (Fig. 53B).



53. A. Solar ray cones for the solstices and the equinoxes.
B. The solar ray cones are similar for every point on the earth (after Pleijel).

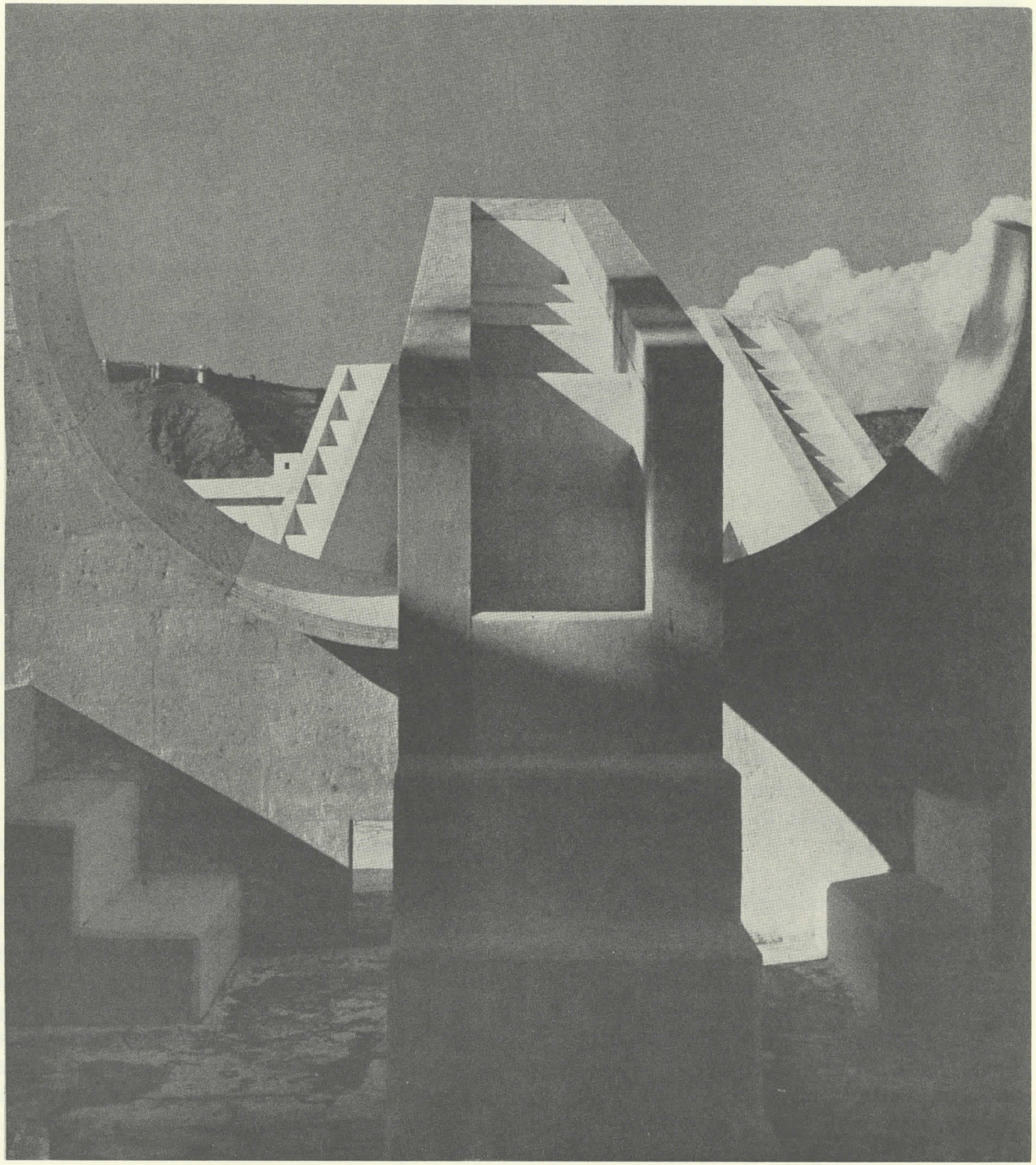
V. SHADING

AND INSOLATION MEASUREMENTS OF MODELS

MEANS of determining the angles at which sunlight will fall on buildings at different places, seasons and times of the day can be categorized as model measurements, and calculative or graphical methods.

Calculative methods will be discussed later in Chapter XII; the methods of model measurements will be treated in this chapter. The great advantage of using models is the directness with which shading or insolation can be observed visually. Situations can be easily changed, perceived and compared. With calculative methods, though they are less visual, the intensities of radiation, highly desirable for exact evaluations, can be additionally defined.

The picture shows one of the sundials of the observatory at Taipur, India, which has a collection of the largest stationary dials in the world. The dials were constructed about 1724 by Jai Singh, Rajah of Jaipur. The shadow-casting edges of the gnomons are marble as are the dial faces.



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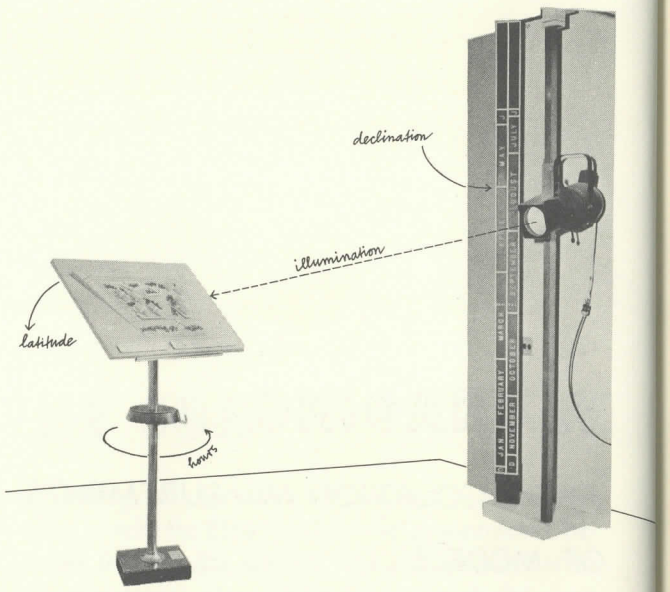
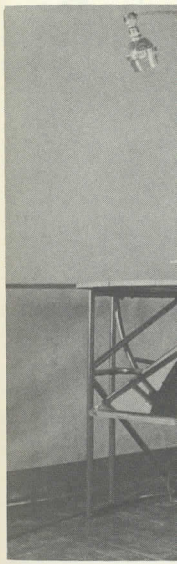


55. Heliodon at Princeton University.



56. Sunmachine

SUN MACHINE TYPES

In using models to determine insolation a light source is needed to represent the sun. The relation between the model and the light source is adjustable to reproduce the actual conditions of light in any given situation.

Three variables have to be adjusted:

A. the latitude variable, which defines the angle of the sun-paths in relation to the geographical location;

B. seasonal variation, which defines the declination of the sun on a given day; and

C. hourly change of the sun from East to West.

For this purpose many instruments have been devised under different names. They may be categorized according to their methods of operation. Those which are mechanically adjustable to the above-mentioned three variables might be called "sun machine" types.

Prof. G. M. Beal, University of Kansas, made a survey in 1954 regarding the types and number of "sun machines" used in the architectural schools. According to his findings, a total of 18 sun machines are in use or under construction at the schools in U.S., Canada and England. The time of building ranged from 1937 to 1953. The types used were:

A. fixed light, model rotated—6 plus 2 under construction.

B. fixed model, flood light moves—5 plus 2 under construction.

C. other types—3 both model and light move.

In addition to the above, various institutions and experimental stations built similar types which fall into these categories.

The British Building Research Station developed a so-called "Heliodon"[7] which consists of a movable table representing the building site and a movable lamp representing the sun. The table revolves about a vertical axis and tilts when revolved about a horizontal axis. The lamp is arranged to slide up and down vertically on a separate calibrated rod.

At Princeton University, the School of Architecture possesses a sun machine built on similar principles which was developed by Prof. R. W. McLaughlin, Director of the School, formerly partner in Holden, McLaughlin and Associates, architects. (Fig. 55)

The "Heliodon" of the Planning and Housing Division, School of Architecture, Columbia University, N. Y., uses the same method.[8]

Prof. Beal, mentioned above, constructed a type with a power-driven lamp rotating around a horizontally placed model. (Fig. 56)

Dr. L. W. Neubauer of the University of California[9] devised a similar instrument, but manually operated, called "Solaranger."

Libbey-Owens-Ford Glass Company constructed two types on similar principles: one, power driven, the other manually adjustable, called the "Solarometer." In both types the model stands on a rotating horizontal surface, while the lamp moves into the proper situation.[10]

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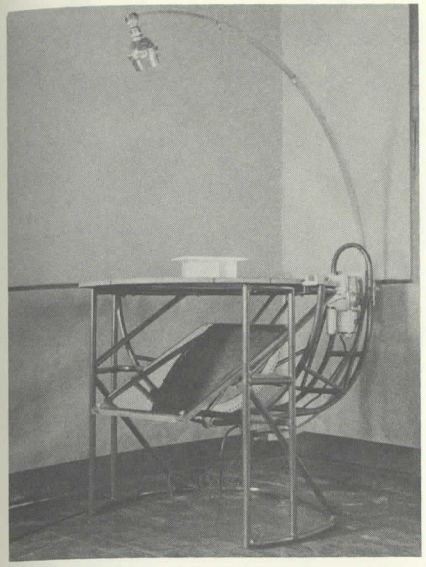
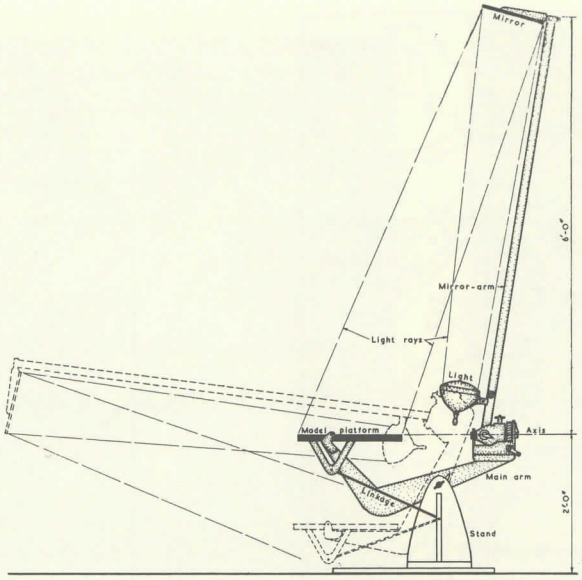
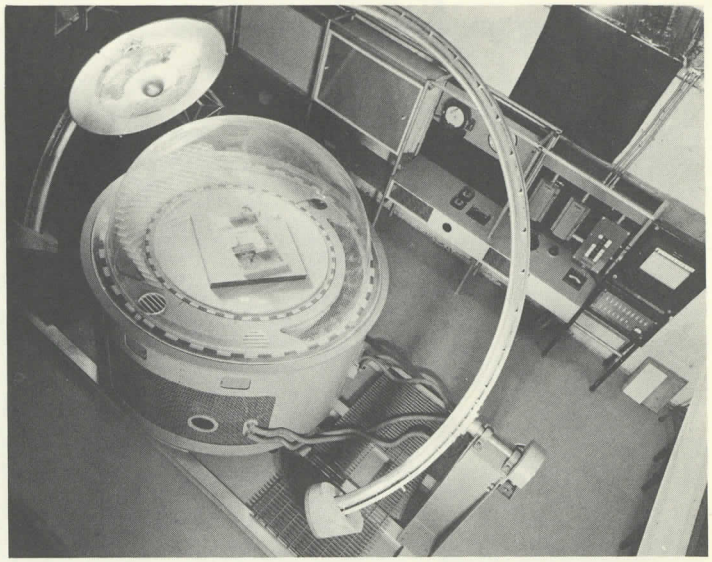


56. Sunmachine at University of Kansas.



57. The Solarscope.



58. Thermoheliodon at Princeton University.

Station developed an instrument called a "Solarscope"[11] in which, once again, the model remains horizontal while the light revolves around it. It differs from the previous types, however, in that the light is reflected from a mirror on a movable arm down to the model, thus minimizing the divergence of the light rays. (Fig. 57)

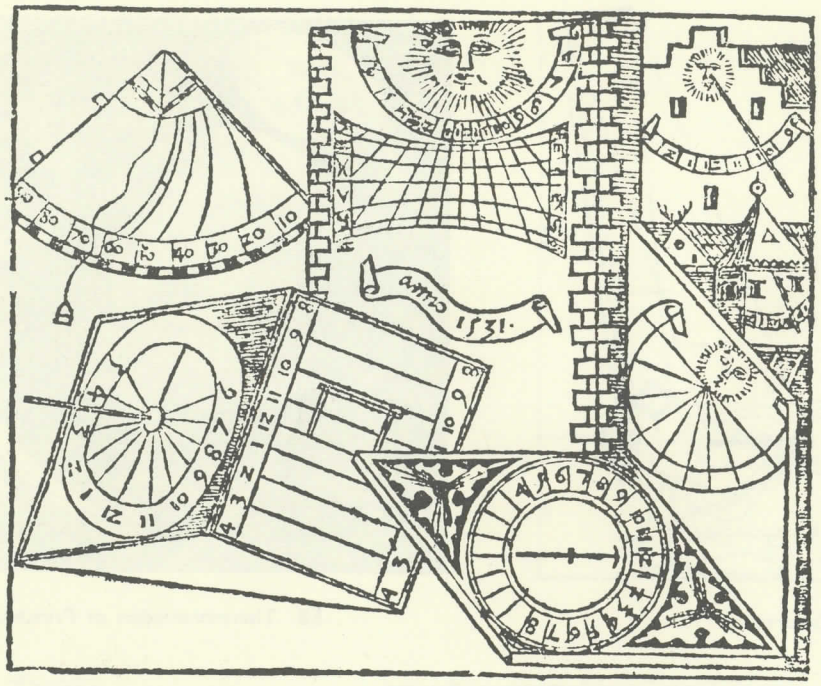
Cornell's College of Architecture calls its type a "Solatron," where the model is placed on a horizontally rotating table, and the lamp is cranked up or down on a fixed arch.

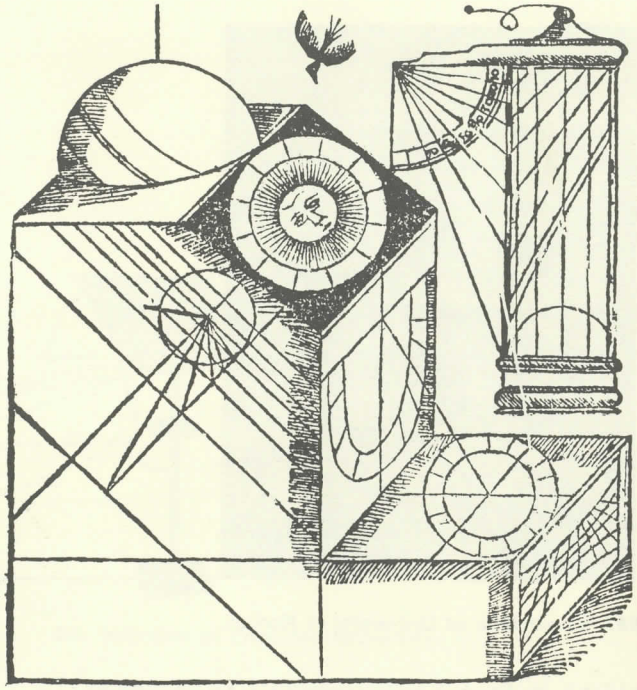
Alfred L. Loomis, Tuxedo Park, N. Y., devised a type in which the lamp is fixed and the platform of the model can be moved to the proper relation.

The "Heliodon" of Johns Hopkins University[12] has the same characteristics as the Loomis model.

The "Thermoheliodon" of the School of Architecture, Princeton University (Fig. 58) has a power-driven lamp rotating around a horizontally situated model. The machine, developed by the authors, has a parabolic reflector four feet in diameter to secure parallel rays on the experimental surface. It differs from the other types in that it is built not only for insolation experiments, but with a heat-lamp as a light-source to make possible the measurement of the thermal behavior of buildings.

All these "sun machines," regardless of how ingeniously or precisely constructed, suffer from two disadvantages. The first is a coherent characteristic; the divergence of the rays of the lamp. The distance between lamp and model alleviates, but does not eliminate, the problem, except in the case where the light-source is as large as the model. This makes accurate measurements difficult, especially with larger models (such as city planning layouts). The second disadvantage lies in their excessive size and their construction cost, both of which limit their use for institutions and experimental stations.





59, 60. Forms of flat sundials and forms of spatial ones, after "Rudimenta Mathematica," Basel, 1531.

SUNDIAL TYPES

There is another possible way to measure shading and insolation on models, which does not work on the principle of moving a light-source, representing the sun, by mechanical adjustments in the place of the sun. If one bears in mind that shadows move exactly opposite the sun, the solution is clear. Any sundial can tell us the position of the shadows. But, while sundials are used to tell time in a given position of the sun, by the same token they can be used in reverse—at any given time, by a sundial's shadow one can determine the position of the sun.

Such instruments may be called "sundial" types.

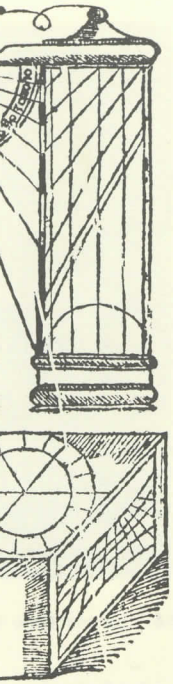
Gnomonics, the oldest knowledge of time-keeping, is a nearly forgotten field today, but it is still very exciting and useful for those who are interested in the graphical projections of sun-paths. It is not the purpose of this report to enter into this field, with its ingenious and innumerable solutions to the problem, though the book of "Sundials" by Mayall and Mayall[13] should be recommended to the curious.

In the vast family of sundials only one type—the horizontal—has been used for shading measurements. This seems to be quite logical, since the dimensions of shadows change in various orientations, provided the dials are flat surfaces.

"Shadowgrams," showing the end-points of the shade of a unit measure on a horizontal surface throughout the year, are basically horizontal dials. Actually these shadowgrams were not devised for model measurements, but rather for calculation purposes. The so-called "cotangent diagram" belongs to this category, on which detailed calculations are possible. It suffers, however, from a basic disadvantage common to all shadowgrams in this classification, namely, that it needs to be of infinite extent to include the whole sky-vault. Kuttner,[14] Grobler,[15] and Beckett[16] have developed usable systems in this field.

Gunnar Pleijel[17] overcame the above disadvantage by constructing his so-called "Little Sundial" with elevated sides making shades measurable up to the horizon plane. It is a very usable and inexpensive, square-shaped instrument. It has only one disadvantage, namely, it is usable only for one given latitude. For other latitudes different calibration is necessary; therefore, this instrument is manufactured for every second degree of latitude.

This disadvantage can be eliminated by the "Shade-dial," an instrument which was developed by the authors.[18]



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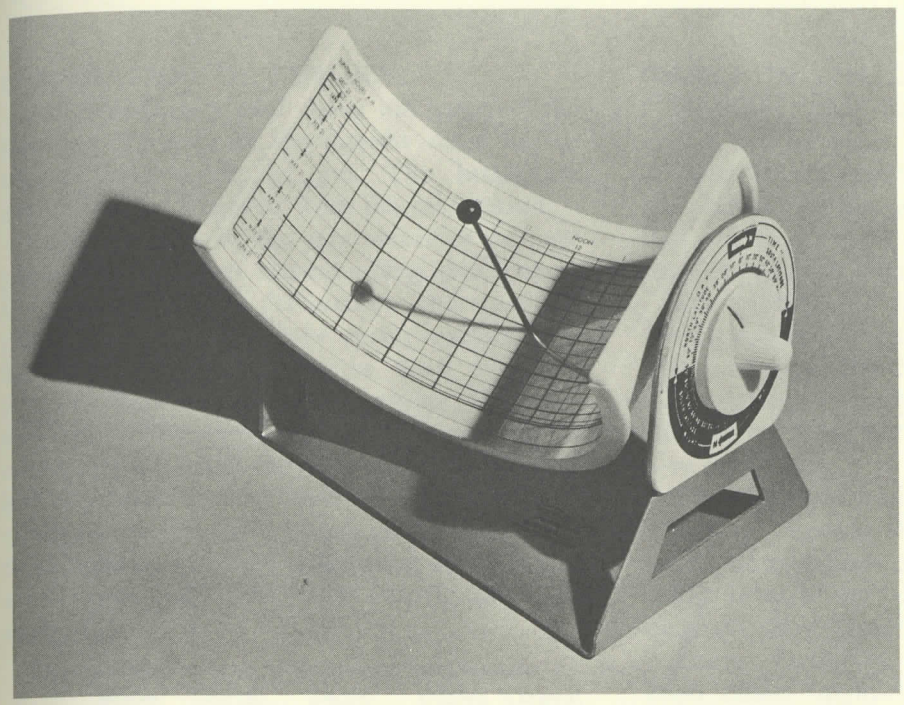
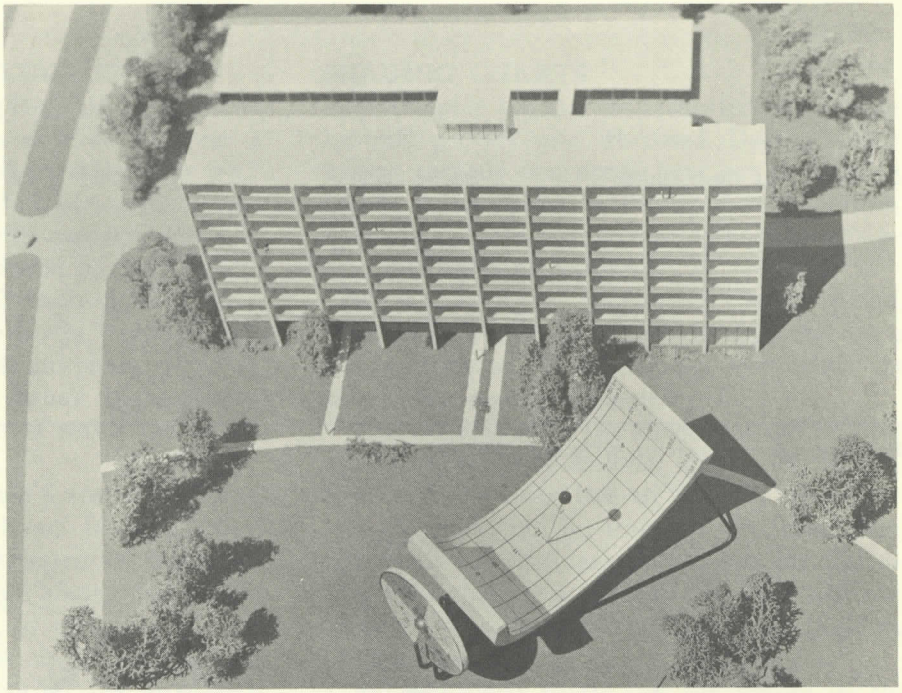


61. The Shade-Dial.



62. The Shade-Dial recording insolation.

THE SHADE DIAL

With the Shade-dial, shading effects or insolation can be determined on models at any geographical location and at any given time. By placing the Shade-dial near to the model on the same surface, they can be oriented together in such a relation to a light-source that the actual position of insolation will be reproduced.

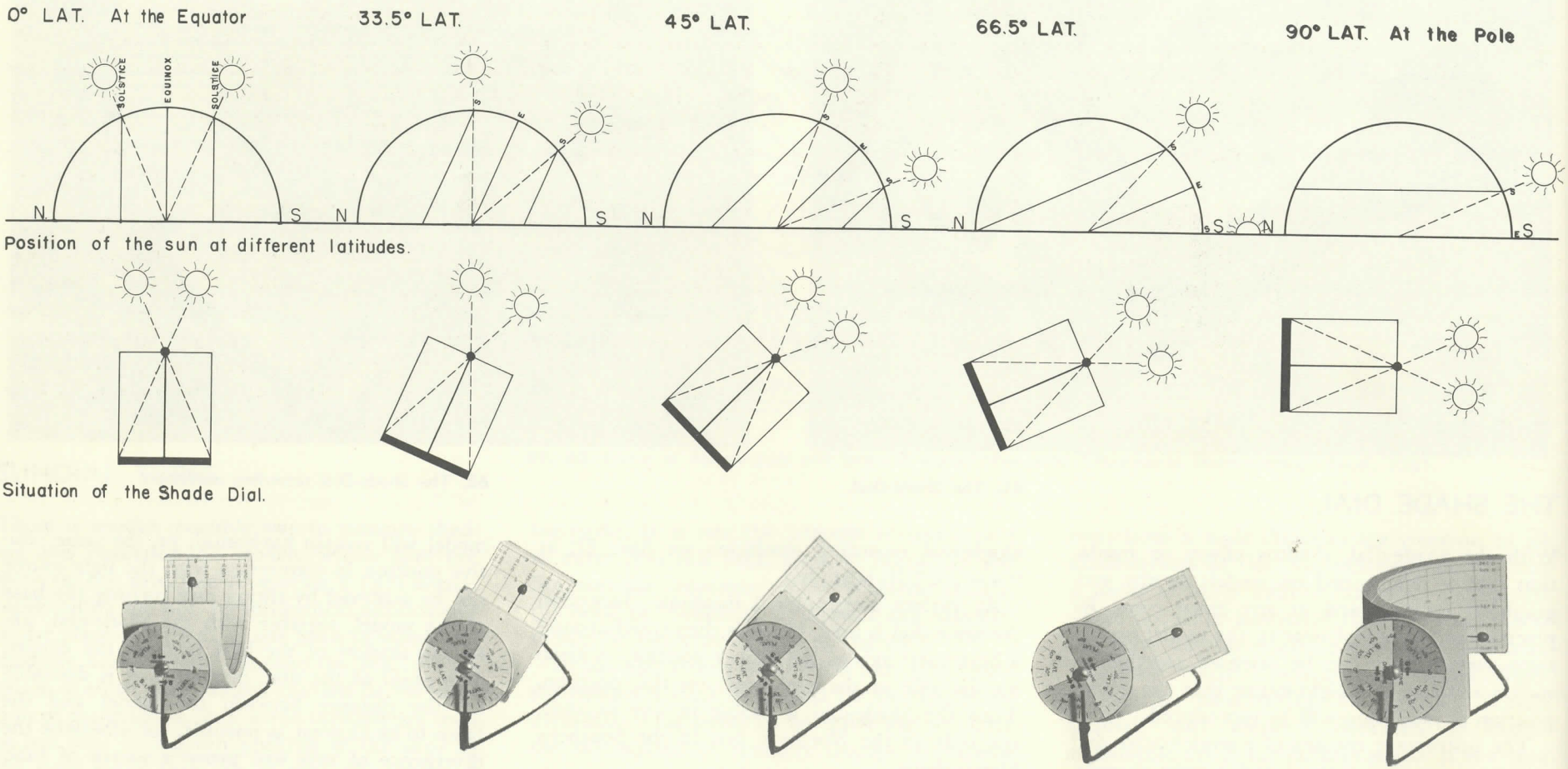
The instrument consists of a semicircular dial calibrated for the seasonal and hourly changes. In the center of this dial a small ball is fitted which, when illuminated, will cast a shadow on the dial. The shadow will show the month and the hour on the dial, which corresponds to the sun's situation at that time. Correspondingly, if one is interested in the insolation at a given time, the shadow of the ball should be situated at this date and hour on the dial, and the model will be illuminated accordingly. (Fig. 61 shows the Shade-dial recording insolation on Apr. 21, at 9 A.M., 42° N. latitude.)

At various geographical locations (latitudes) the same dial is used, but it is then tilted around a horizontal axis to the proper position. A knob on the side of the dial indicates this position. Thus the Shade-dial is usable in any latitude, not only in the Northern but in the Southern Hemisphere.

LIGHT SOURCE

The source of light can be either an ordinary table lamp, or the natural sun itself. In the case of the former, if the lamp is moved the model will remain horizontal; or, the same relative position in connection with the light-source can be achieved by tilting and turning the base of the model, together with the Shade-dial, until the shadow of the ball falls on the desired date point of the dial. Naturally, it is desirable for the distance between the model and the lamp to be as great as possible; for otherwise the divergence of rays will prove a source of inaccuracy. Ten feet is recommended as a minimum distance, where the divergence on a two-foot model will be 6 degrees.

This disadvantage will be eliminated if the natural sun is used as a light source. For precise measurements, therefore, this latter method is recommended. (Fig. 62 shows the study of a model with sunshine on Aug. 21, at 2:00 P.M., 30° N. latitude.)



63. The Shade-Dial's positioning for different northern latitudes.

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CALIBRATION

Date	Declination
Jun 21	+23°27′
11	+23°05′
1	+22°02′
May 21	+20°09′
11	+17°50′
1	+15°01′
Apr 21	+11°48′
11	+ 8°15′
1	+ 4°28′
Mar 21	+ 0°10′
11	− 3°47′
1	− 7°39′
Feb 21	−10°37′
11	−14°05′
1	−17°09′
Jan 21	−19°57′
11	−21°51′
1	−23°02′
Dec 21	−23°27′

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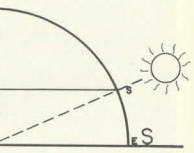
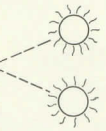
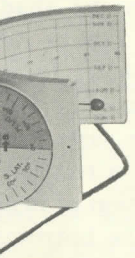






CALIBRATION OF THE DIAL

The semicircular dial shows the hours of the day and the days of the months according to the declination of the sun. The hours are marked in 15° intervals from the centerpoint.

The date lines, by the very nature of the sun-path, represent two corresponding dates when the sun has the same declination. Therefore one side of the dial shows the spring months and the other the summer months. Each month is divided into approximately 10-day intervals, showing the 1st, 11th and 21st day lines. Due to certain irregularities between the calendar year and the astronomical data, a compromise is necessary in the calibration, as shown in the table following. These differences being rather small (not exceeding $0.68° = 41'$), they are negligible.

CALIBRATION OF DIAL WITH UNIFIED DECLINATION:

Date	Declination	Corresp. Date	Declination	Unified Calibr.	Tangent Calibr.
Jun 21	+23°27′	Jun 21	+23°27′	+23°27′	0.434
11	+23°05′	1	+23°08′	+23°06′	0.428
1	+22°02′	11	+22°09′	+22°03′	0.405
May 21	+20°09′	Jul 21	+20°31′	+20°20′	0.371
11	+17°50′	1	+18°05′	+17°87′	0.324
1	+15°01′	11	+15°21′	+15°11′	0.271
Apr 21	+11°48′	Aug 21	+12°12′	+12°00′	0.212
11	+ 8°15′	1	+ 8°22′	+ 8°18′	0.145
1	+ 4°28′	11	+ 4°39′	+ 4°33′	0.079
Mar 21	+ 0°10′	Sep 21	+ 0°47′	+ 0°28′	0.008
11	− 3°47′	1	− 3°06′	− 3°26′	0.060
1	− 7°39′	11	− 6°57′	− 7°16′	0.127
Feb 21	−10°37′	Oct 21	−10°38′	−10°38′	0.187
11	−14°05′	1	−14°22′	−14°13′	0.253
1	−17°09′	11	−17°22′	−17°15′	0.310
Jan 21	−19°57′	Nov 21	−19°53′	−19°55′	0.362
11	−21°51′	1	−21°47′	−21°48′	0.400
1	−23°02′	11	−22°59′	−23°00′	0.424
Dec 21	−23°27′	Dec 21	−23°27′	−23°27′	0.434

(Basic data after the American Ephemeris)

MARKS ON THE LATITUDE KNOB

When the Shade-dial is placed on or near the model on the same horizon level (e.g. on a drawing board) care should be taken that both are oriented in the same direction. This means that the South sign on the model should be parallel with the sign indicated on the knob.

The calibrations on the knob show "North Latitudes" and "South Latitudes," referring to the Northern or Southern Hemisphere (Fig. 63). Thus the knob should be turned to the proper latitude mark for the latitude which the model is to investigate.

The dial shows hours from 6 A.M. until 6 P.M. The time between these hours is called "daytime." If somebody is interested in insolation before or after the "daytime hours," the Shade-dial will show these also. In this case, the adjustments should be made on the part of the knob called "night-time." After the Shade-dial is turned around 180 degrees, the "night-time" South sign will be parallel with that of the model. Otherwise the procedure is the same as before.

As shown, the Shade-dial is a simple, small, and inexpensive instrument which can be obtained by any architect or engineer.[19] It makes possible the study of any situation of insolation, and has an advantage over the "sun machines" in that it can be used under the parallel rays of the natural sun.

Furthermore, the Shade-dial can not only make possible the study of the distribution of shade and sunshine, but it can also show simultaneously that isolation in a given situation is necessary or disadvantageous. This characteristic of the Shade-dial is the topic of the next section.

SHADING CHARTS

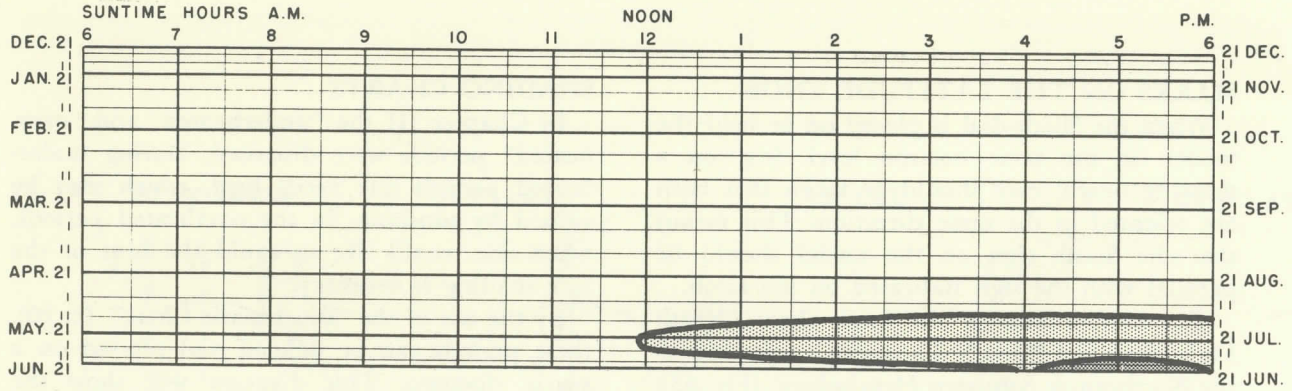
In Chapter III the "underheated" and "overheated" periods were discussed. During underheated periods one needs heat, which may be gained by sunshine. In the overheated periods, when one would like to avoid the heat of the sun, shading is necessary.

By the use of the "Bioclimatic Chart" (p. 20), these periods can be defined and plotted on a yearly diagram. This diagram will show the times when shading is needed.

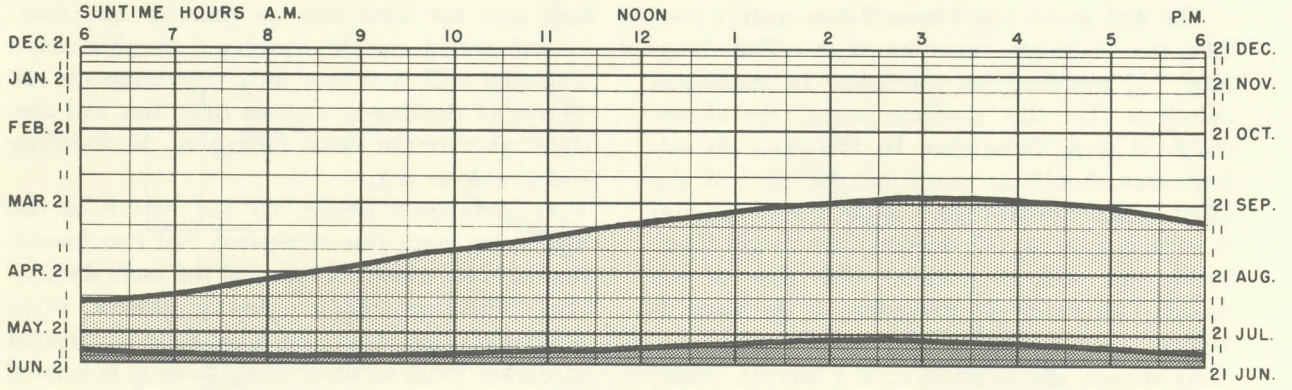
The calibration of the Shade-dial can be used as a chart, with the seasonal declination as ordinate and the hour line as abscissa. The overheated period can be translated on this chart. The dial will then not only determine the direction of shading at a given time, but will also show whether the shade falling on the building is desirable or not.

As mentioned before, by the nature of the dial chart every line represents two corresponding dates on which the sun has the same declination. Therefore, the overheated period, when plotted on this chart will have areas (indicated in darker tone) to show when shading is needed on both of the corresponding dates. Other areas (indicated in lighter tone) will show when shading is needed only on one of corresponding dates and sunshine on the other. The remainder of the chart will show those dates on which sunshine is needed on both of the corresponding dates.

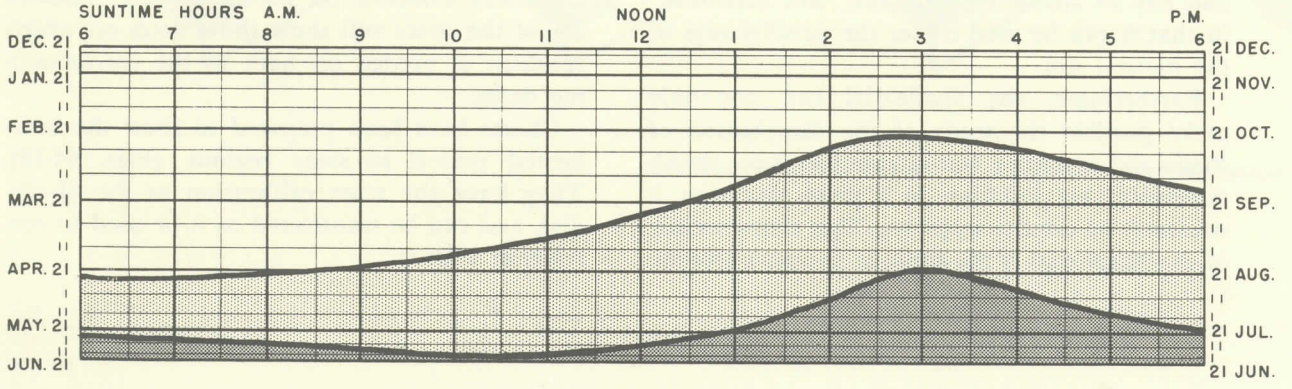
Charts have been prepared to show the overheated period in some regions (Figs. 64-72). They have the same calibration as the Shade-dial, and can be transferred to it or used in correlation with it.



64. Northern Minnesota, 48° N. Lat.

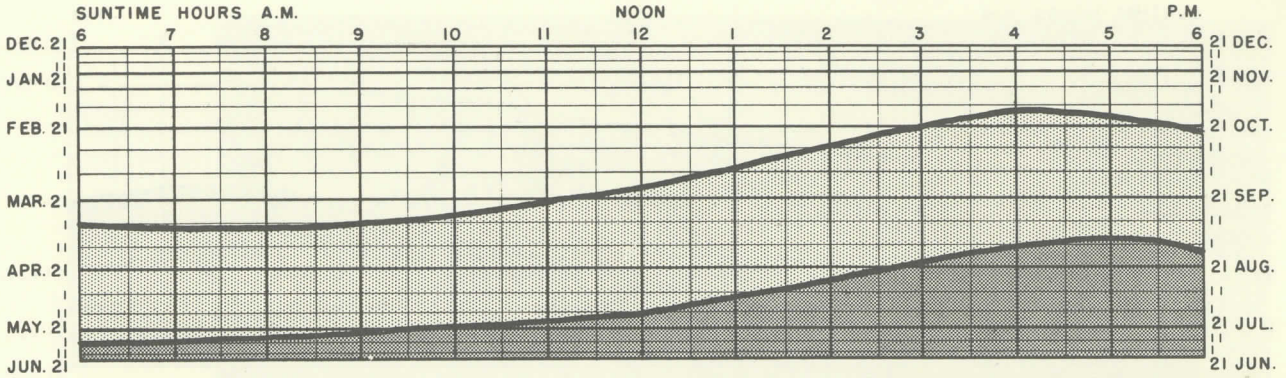


65. New York-New Jersey area, 40° N. Lat.

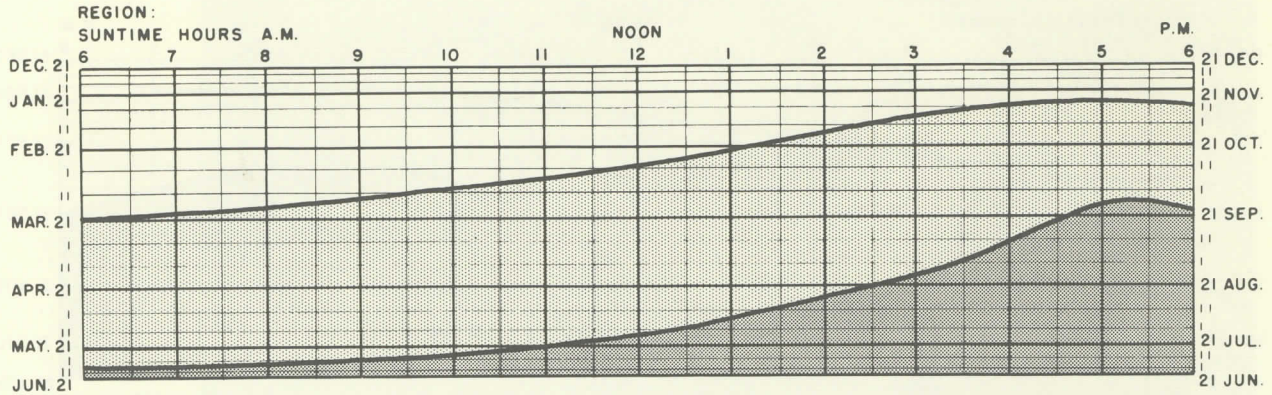


66. Amarillo, Texas, 35° N. Lat.

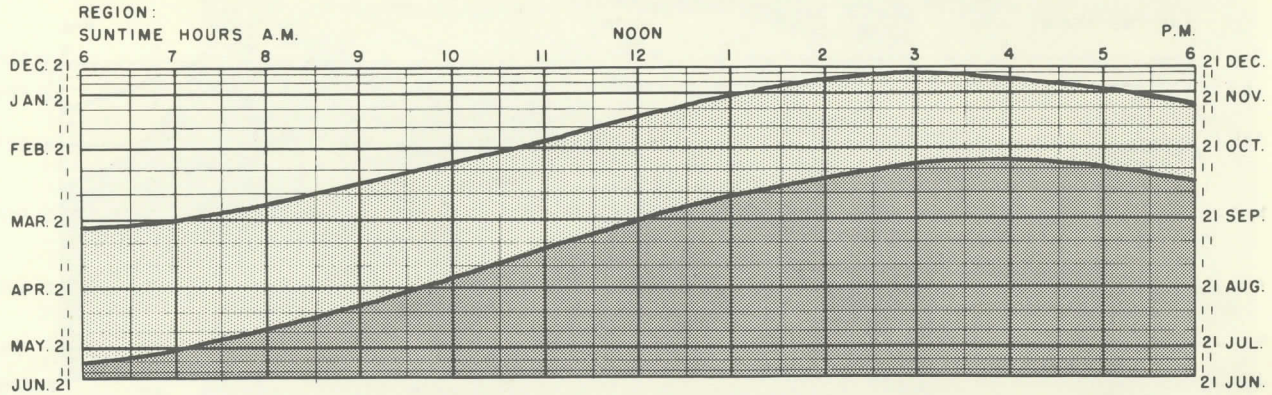
SHADE DIAL CHARTS WITH INDICATED OVERHEATED PERIODS



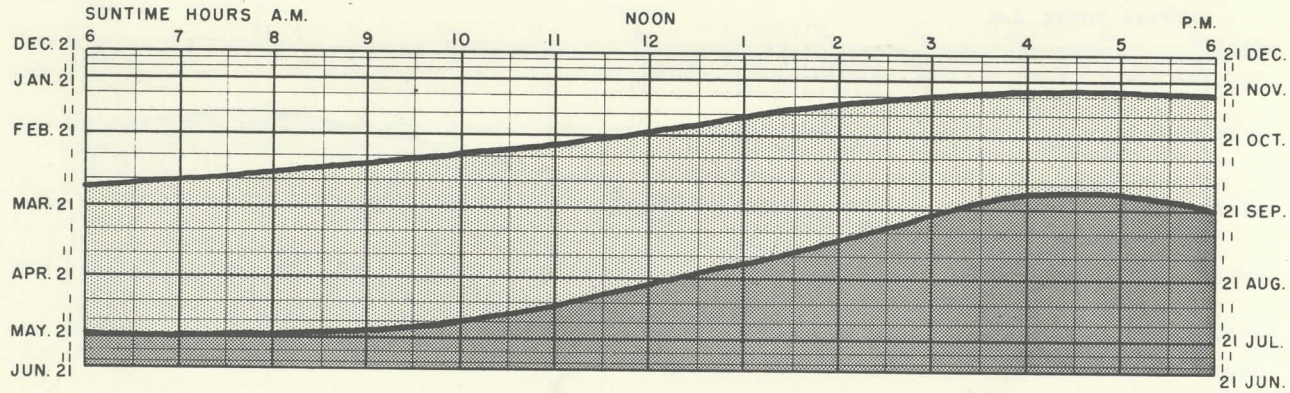
67. Dallas, Texas, 33° N. Lat.



68. Austin, Texas, 30° N. Lat.

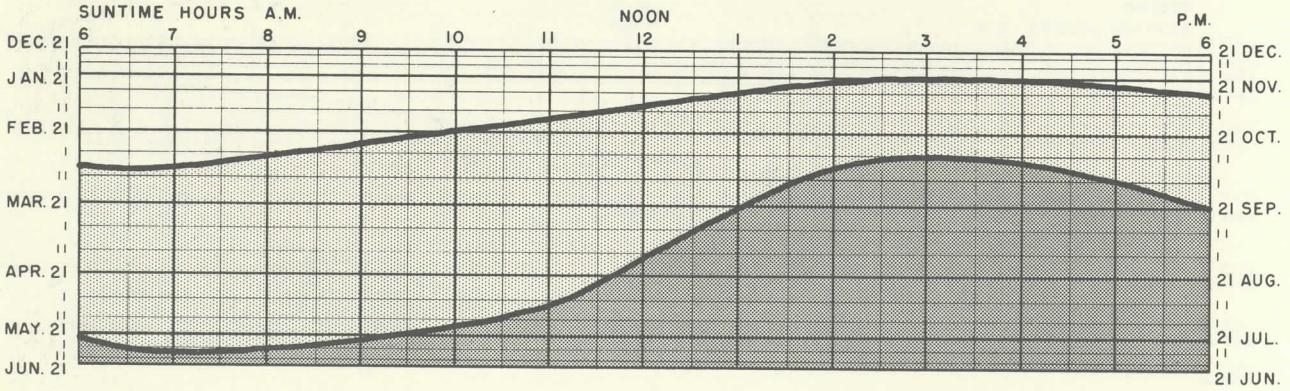


69. Phoenix, Arizona, 33½° N. Lat.

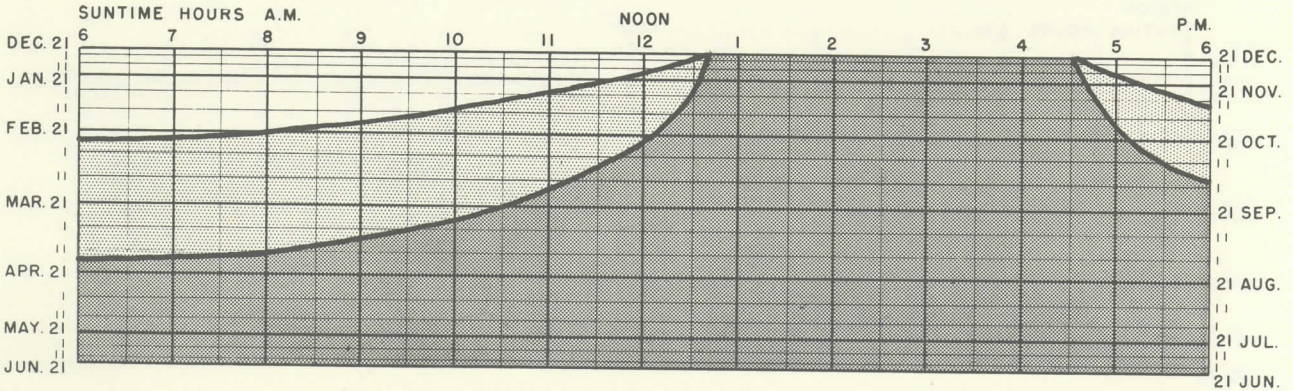


SHADE DIAL CHARTS WITH INDICATED OVERHEATED PERIODS

70. New Orleans, Louisiana, 30° N. Lat.



71. Houston, Texas, 29½° N. Lat.



72. Brownsville, Texas, 26° N. Lat.

PRACTICAL

SHADE-DIAL

A. Place the Sh
base plate so tha
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the model.
B. The Latitude
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C. The model,
should be tilted
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the ball falls on
is desired to be
shadows on the
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In the case of
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heat-balanced so
case of a town-pl
tion or shading
ings or playgrou
and orientation

The examples
measurements of

Fig. 73. Study of
Feb. 21 at 10 A.M

Fig. 74. Study of
on April 21 at 8

Fig. 75. Study o
latitude on Oct.

ICATED

. Lat.

PRACTICAL APPLICATION OF THE SHADE-DIAL

A. Place the Shade-dial on the model on its base plate so that the bottom of the instrument is parallel with the horizontal plane of the model. The "North" sign on the Latitude-knob should point in the same direction as that of the model.

B. The Latitude-knob should be set to the latitude where the building in question is located.

C. The model, together with the Shade-dial, should be tilted and turned to a position relative to the light source such that the shade of the ball falls on the dial at the time mark which is desired to be studied. The light, shades and shadows on the model will correspond to those on the actual building at the time shown by the dial.

With the help of the shading charts the Shade-dial becomes a design tool for heat control; a solution can be reached in shading or insolation according to the cooling or heating needs.

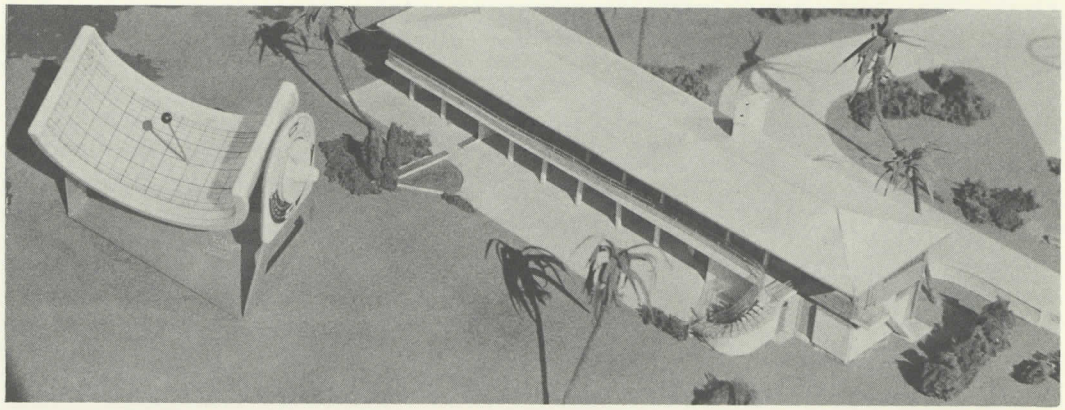
In the case of an elevation, by changing on the model the dimensions of the shading devices according to the needs shown by the chart, a heat-balanced solution can be designed. In the case of a town-planning project, desirable insolation or shading effects can be studied of buildings or playgrounds determining their location and orientation in this way.

The examples on this page show insolation measurements of models:

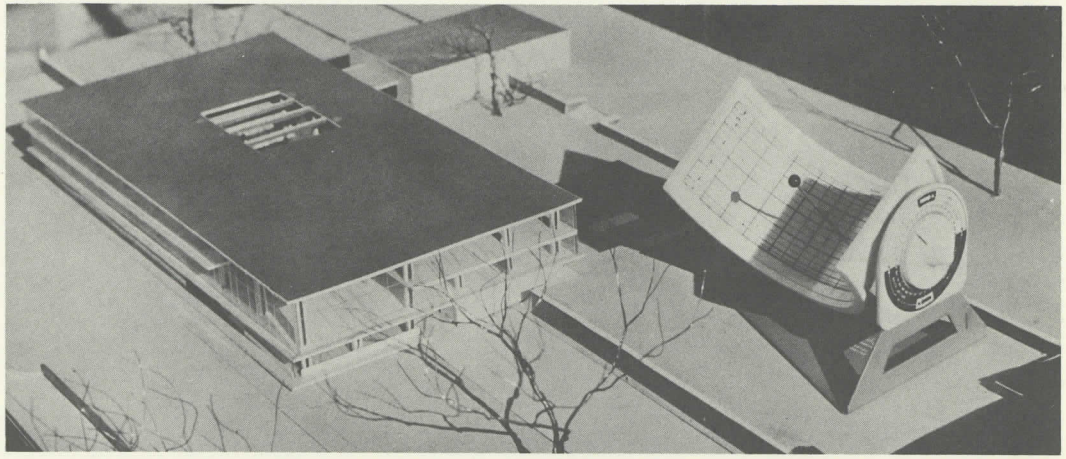
Fig. 73. Study of a house at 32° N. latitude on Feb. 21 at 10 A.M.

Fig. 74. Study of a building at 40° N. latitude on April 21 at 8 A.M.

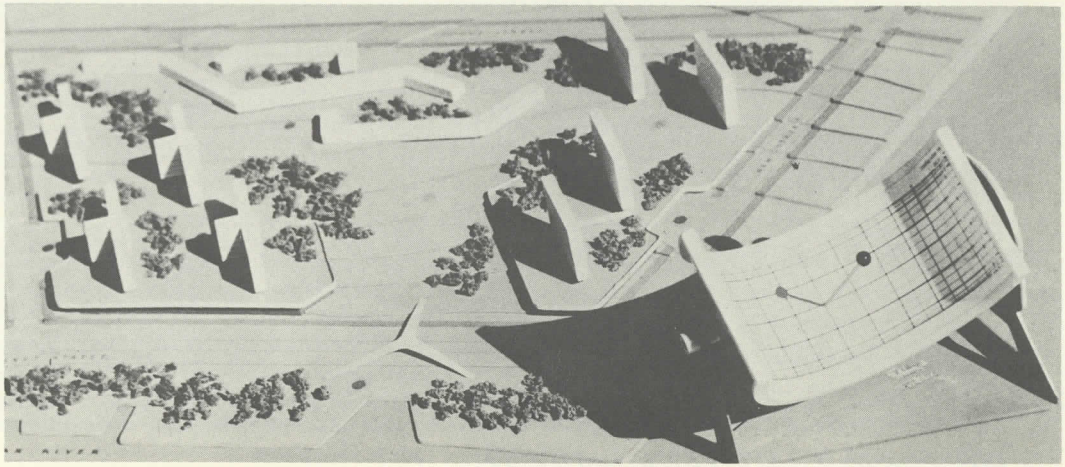
Fig. 75. Study of a housing scheme at 42° N. latitude on Oct. 21 at 11 A.M.



73.



74.



75.

VI. SOLAR AND STANDARD TIME

ALL charts and diagrams used in this study are calibrated according to the sun as it appears, and measure therefore by the so-called "apparent" or "solar" time. In daily life, however, time is measured by "standard" time, which differs somewhat from solar time.

For measurements of shading devices or insolation, this difference is unimportant, for the position and the duration of the sunshine will be exactly the same in both types of time-keeping. If, of course, for some reason it is necessary to learn the position of the sun at a given time as measured by the clock, some conversions are necessary:

A. The correction of the sun-time to the mean time of the locality by the application of the equation of time, or "analemma":

B. The correction of the mean time of the locality to standard time, by the difference in longitude to the standard time meridian. This degree difference must be subtracted, if the location under consideration lies east of the standard time meridian, and added if it is west. The "4" in the formula is the number of minutes of time required for the sun to pass over 1° of longitude.

The formula to convert Solar time to Standard time, or vice versa:

Standard time = Solar time + Equation of time + 4 (Difference in Longitude).

EQUATION OF TIME

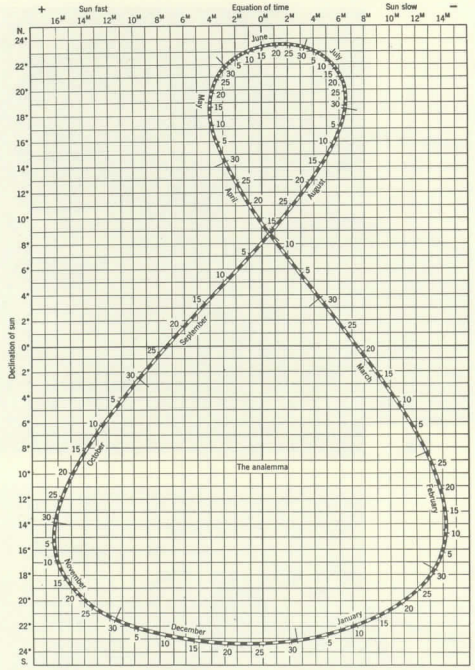
The sun's velocity varies throughout the year from the combined effect of two principal causes: the varying speed of the Earth due to the eccentricity of its orbit, according to Kepler's second law, and the obliquity of the ecliptic. The term "apparent solar time" is applied to the system of days and hours which is governed by the sun itself, and which is therefore continually changing in value from day to day. The term "mean solar time" applies to the system of days and hours mathematically computed in such a way as to give the average value to every hour and day. All clocks and watches in general employ mean solar time. The difference in value between apparent and mean solar time is known as the "equation of time." The sun is said to be "fast" when it arrives over the meridian before 12:00 noon by mean solar time, and the equation of time is said to be "positive." When the sun is "slow," or arrives late over the meridian, the equation of time has a "negative" value. It can be represented graphically by a diagram known as the analemma (Fig. 76).

TABLE SHOWING EQUATION OF TIME IN MINUTES FOR THE DAYS CALIBRATED ON THE CHARTS:

(Compiled from American Ephemeris)

	1st	11th	21st		1st	11th	21st
JAN	+ 3.6	+ 8.0	+11.4	JUL	+ 3.6	+ 5.3	+ 6.2
FEB	+13.7	+14.4	+13.8	AUG	+ 6.2	+ 5.1	+ 3.1
MAR	+12.5	+10.2	+ 7.4	SEP	+ 0.0	— 3.3	— 6.8
APR	+ 4.0	+ 1.1	— 1.2	OCT	—10.2	—13.1	—15.3
MAY	— 2.9	— 3.7	— 3.6	NOV	—16.3	—15.9	—14.1
JUN	— 2.4	— 0.6	+ 1.5	DEC	—11.0	— 6.8	— 2.0

THE ANALEMMA



76. The Analemma.

The values of the equation of time are plotted to the right or left of the vertical centerline, depending upon whether the sun is fast or slow. Values for the sun's declination are plotted above or below a horizontal centerline, and range 23°27′ south to 23°27′ north. Therefore, for every calendar day there is a point on the analemma which shows simultaneously the equation of time and the sun's declination.

STANDARD TIME

The watch time of everyday life is called standard time, because the time of all places within certain zones refers to one meridian near the center of that particular zone, which is called the "standard time meridian." This local time is arbitrarily given to the zones on both sides of the meridian. Thus, all clocks within the belt are set to a single time.

Standard time meridians are 15° apart, so that adjacent zones will have standard times differing by one hour. The four time zones in the U.S. are located on the 75th (Eastern Standard Time), 90th (Central Standard Time), and 120th (Pacific Standard Time) meridians. It is evident that the mean solar time will coincide with the standard time only on these meridians. Each degree of longitude difference from these meridians indicates 4 minutes in time, which has to be added or subtracted from the standard time to determine the mean solar time of the locality.

With the formula mentioned above, conversions can therefore be made to translate standard time to solar time and vice-versa.

VII. GRAPHICAL METHODS TO DETERMINE THE SUN'S PATH

THERE are several methods to determine the position of the sun in relation to the earth. Many of them are based on numerical or tabular calculations, others on graphical methods. Any calculative method, though preferable where extreme punctuality is important, as in celestial navigation, proves to be so time-consuming that it is impractical in architectural use. In most cases furthermore, where not only the sun's position is of interest, but also its relative position to an elevation, combined with the screening effect of an overhang, calculations become extremely complicated and therefore graphical methods are to be preferred. Hence, the following description will be limited to graphical diagrams.

Some simplifications are used below in the numerical values for the diagrams (as in the unified declination and dates, described on p. 31). Since the differences are rather small, they are negligible in practical use. All diagrams are valid for the Northern as well as the Southern Hemisphere, provided the compass points are changed properly. If in the text the location is not specifically mentioned, it refers to the Northern Hemisphere.

77. From "Rudimenta Mathematica," Basel, 1531.

BIBLIOTECA CASTELLO DEL VALENTINO FACOLTÀ DI ARCHITETTURA TORINO

THE SUN'S PATH ACROSS THE SKY

The changing position of the sun from hour to hour and from day to day is most easily visualized if the point of observation is imagined to be stationed on a flat surface tangential to the earth and surrounded by a hollow hemisphere, the sky-vault, on which the sun moves in a circular path. (Fig. 78) This is actually how the sun appears from the earth's surface, moving in an arc over the sky. The tangential surface is the horizon, and its imaginary intersection with the sky-vault is called the horizon line. The point in the sky vertically over the observer is the "zenith" and the opposite point underneath is called the "nadir." On the sky-vault the sun's movement will describe circles, which are the intersections of the solar ray cones, described above, and the sky-vault. The intersection lines will be circular on the surface of the vault, with the center point on the axis of the cone. These are called the sun-paths. The sun-path will change its position in parallel circles between the winter and summer solstices according to the date and its declination.

The hour-lines of the same time of day on the surface of the sky-vault are great circles going through the intersection point on the axis of the cones with the vault, which represents the pole of the sky. The hour lines are 15 degrees apart from each other on the vault and the 12 noon line lies on the north-south direction.

SUN-PATH DIAGRAMS

There are several different systems of projecting the imaginary sky-vault with the sun-paths on a plane. Some of them project it on the surface of a cylinder, others on planes parallel with the horizon. In principle there could be as many systems as there are map projections. However, further investigations will be based only on the so-called "sun-path diagrams," because they have more advantageous characteristics than other systems.

The diagrams of the "sun-path" system show the sky-vault projected on a plane parallel to the horizon plane. On the resulting diagram the horizon line appears as a circle, and the sun-path as various curves depending on the method of projection and the proper latitude (Fig. 79).

METHODS OF PROJECTION

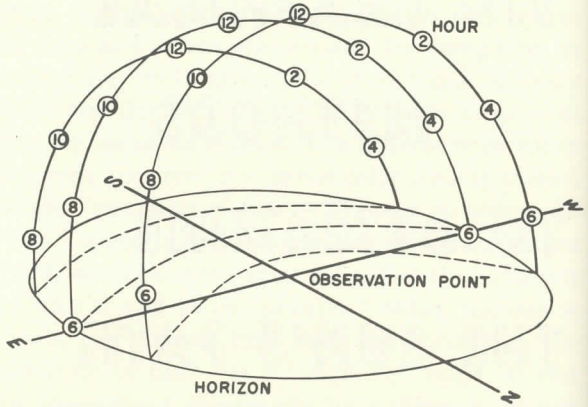
Sun-path diagrams have been employed for sun calculations by astronomers since ancient times (Figs. 80 and 81). This involves the projection of a hemisphere onto a plane, and cannot be accomplished without distortion. Recently used methods of projection are the orthographic, the stereographic, and the equidistant.

ORTHOGRAPHIC PROJECTION

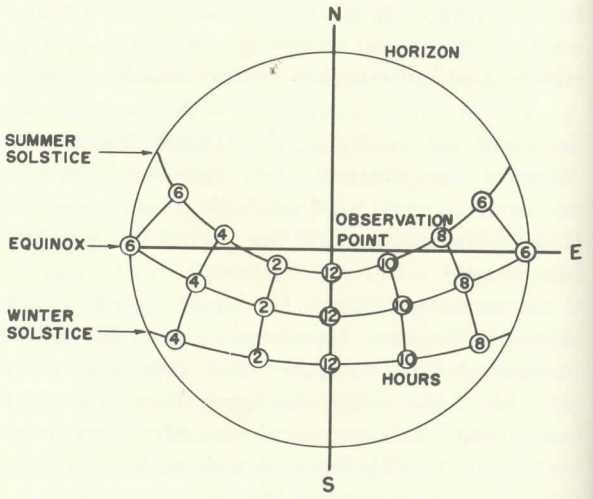
This is a geometrically correct vertical projection of the sky-vault onto the horizon plane, which was used by Molesworth[20] and later suitably modified by Waldram.[21] It is a usable method, but suffers from the disadvantage of severe contraction toward the edges, which makes accurate plotting nearly impossible in these outer areas. A small circle facing the observation point in this projection will increase in one diameter, while the other will diminish, until at the edge of the field a circle is represented by a line. Fig. 82 shows the plotting of the sun-paths in this projection for 40° N. latitude. The contractions are noticeable at the edges, which become worse at more northern latitudes.

STEREOGRAPHIC PROJECTION

This method is extensively used, in which the sun-paths on the sky-vaults are projected, with the nadir as a center, down onto the horizon plane. The stereographic projection has the advantage of producing no distortion of outline; that is, a small circle facing the observation

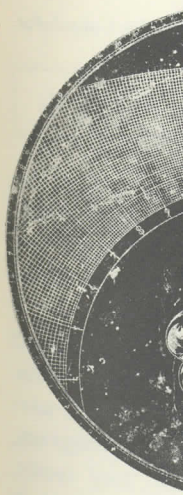


78. Half sphere of the imaginary sky-vault with the sun-paths. The projections of the sun-paths are shown in dashed lines on the horizon plane.

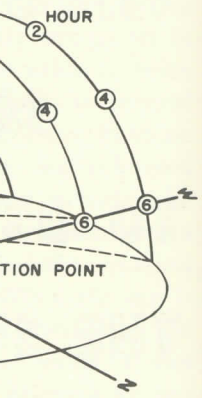


79. Projected diagram of the sky-vault, called "sun-path diagram."

80. A diagram, w
a spherical surface
Mathematica," Bo

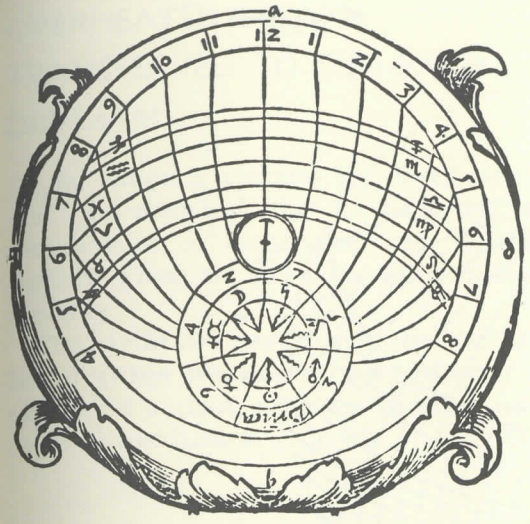


81. Sun slide-rule
(by Oughtred, 163

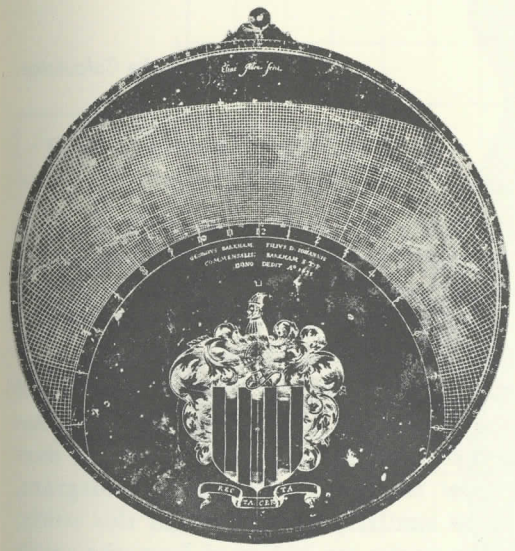


sky-vault with the
-paths are shown in

vault, called "sun-



80. A diagram, which shows the shadow paths on a spherical surface in a flat projection ("Rudimenta Mathematica," Basel, 1531).



81. Sun slide-rule from the seventeenth century (by Oughtred, 1635).

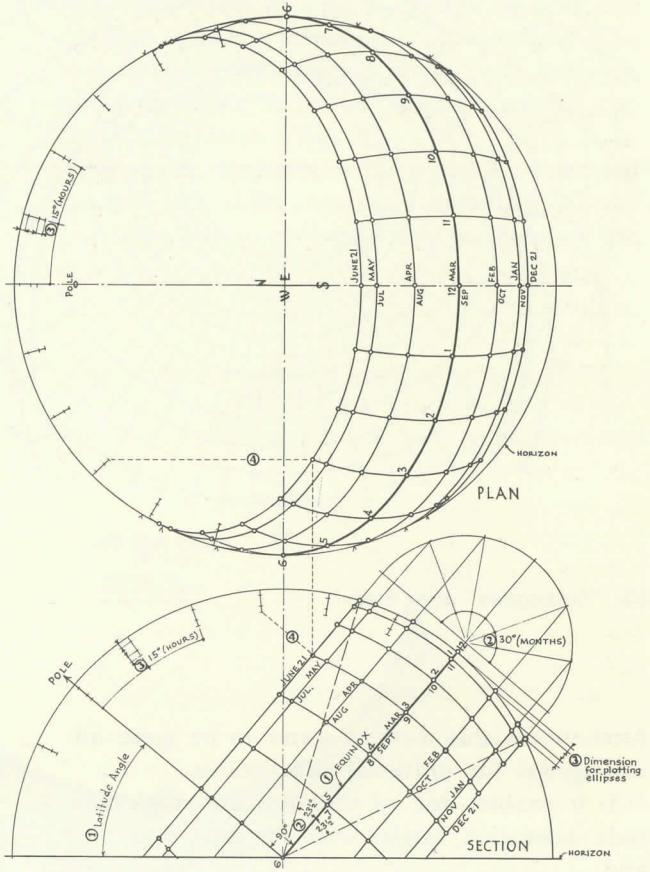
point (as do the sun-paths) will always be a circle whether it is recorded in the center or at the edge of the projection, but its diameter will increase the nearer its position to the edge. Here the altitude circles are more densely spaced toward the center and less so toward the edges. This characteristic gives excellent readability for low angles (surrounding objects) but less favorable for plotting high angles (overhangs, etc.).

The Australian Commonwealth Building Station[22] uses the stereographic projection, as do the Industrial Welfare Division of Australia[23] and the South African Building Institute.[24] It must be mentioned that their research has not only improved the method, but by using sun-angle protractors they have actually made shading device measurements practicable. Gunnar Pleijel also uses this method of projection in his excellent publications.[25] Fig. 83 shows one of his "sun-diagrams" for 56 degrees N. latitude where South is located on the upper part of the chart. Note the contraction of altitude angles toward the center of the chart.

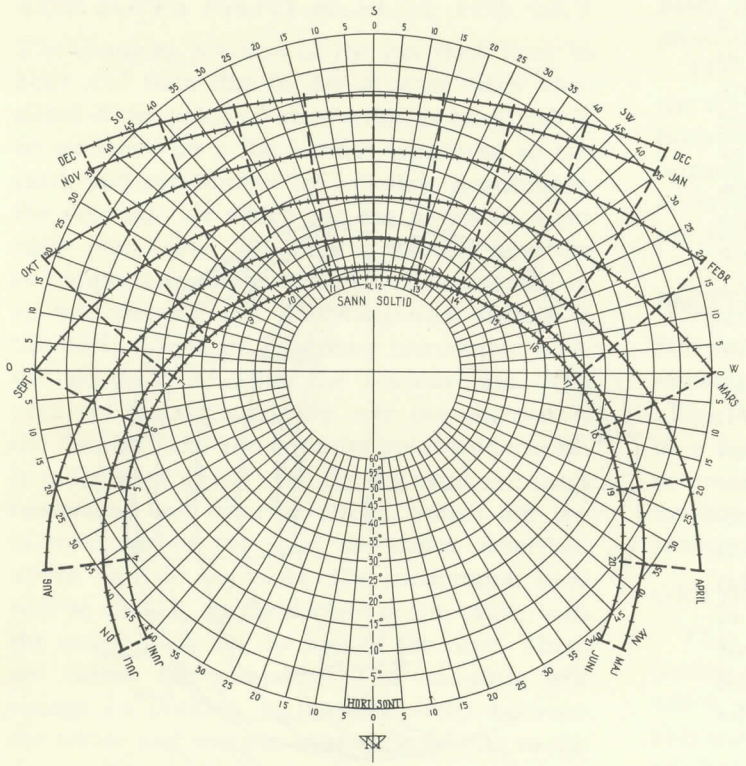
EQUIDISTANT PROJECTION

This is another very satisfactory method, where the altitude angles appear on the diagram equally spaced. This characteristic assures equal readability for high or low angles, and makes plotting easy. A small circle facing the observation point will be flattened out into an ellipse-like figure when it is near the edge, one diameter remaining always the same, the other increasing until it is $\pi/2$ times as great.

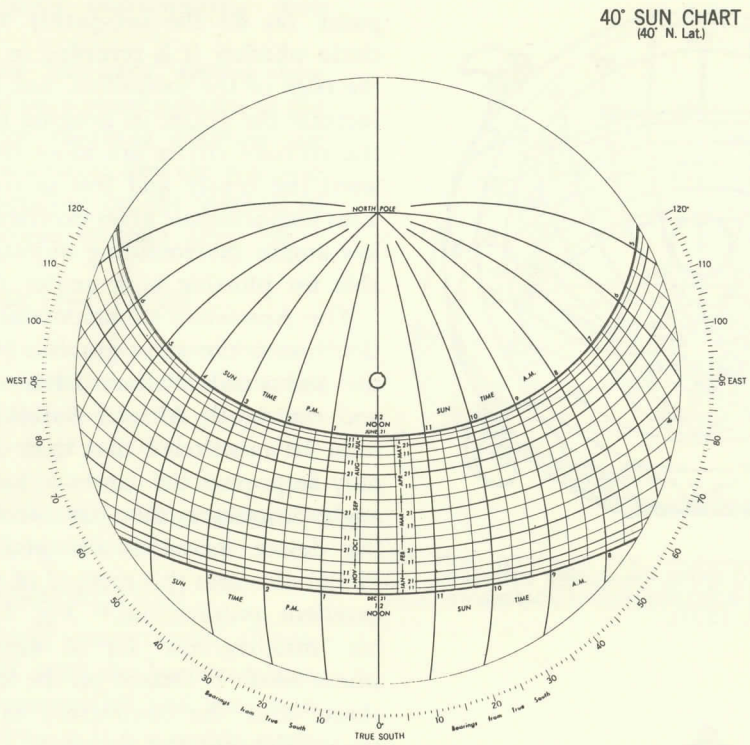
Irving F. Hand[26] described this method, and the Libbey-Owens-Ford Glass Co. produced excellent diagrams in this projection, called the "Sun Angle Calculator."[27] The availability and wide use of this calculator in the United States is such that the further diagrams in this book are constructed in the equidistant projection;



82. Sun-path diagram construction (after J. Rannels).

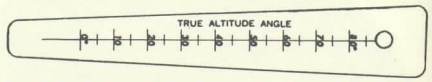


83. "Soldiagram" after Pleijel.



84. A. "Sun Angle Calculator" after Libbey-Owens-Ford Glass Co.

B. Cursor of the Calculator.



furthermore this method seems to be more advantageous for universal use because:

1. it enables one to plot low and high altitude (elevation) angles with the same accuracy, and

2. the accuracy of the projection is also the same for any latitude, independent of whether the sun-paths are at a low or high altitude.

It would be desirable to establish, by international agreement, a unified method of projection (and size of diagrams). The advantages of such a norm, enabling the use of any overlays developed at research laboratories anywhere, are evident.

Fig. 84A shows a sun-path diagram of the Libbey-Owens-Ford "Sun Angle Calculator" for 40° N. latitude. The curved lines indicated by days and months of the year represent the sun-paths on the dates shown. Lines "radiating" from the North Pole indicate the hours. Between the hour lines are lighter lines indicating twenty-minute intervals. Fig. 84B is a cursor which pivots about the center point on top of the diagram. It has an equally graduated scale on which the altitude of the sun can be read in any position.

The sun's position with reference to the horizon is usually expressed by altitude and azimuth. Altitude is the angular distance above the horizon measured perpendicularly to the horizon. It has a maximum value of 90 degrees at the zenith, which is the point overhead.

Azimuth is the angular distance measured along the horizon in a clockwise direction. Astronomers measure it from the south point, navigators from the north point. In this diagram, however, as similarly throughout in this study, the bearing angles are indicated from the south point, as horizontal measurements, instead of the azimuth angles. This calibration proved to be more practicable in architectural use.

OVERHEATED PERIOD TRANSFERRED TO SUN-PATH DIAGRAM

In the foregoing chapters the "overheated period" was described; that is, the period when the sunshine is bothersome, and should be avoided. These are the times when shading is necessary.

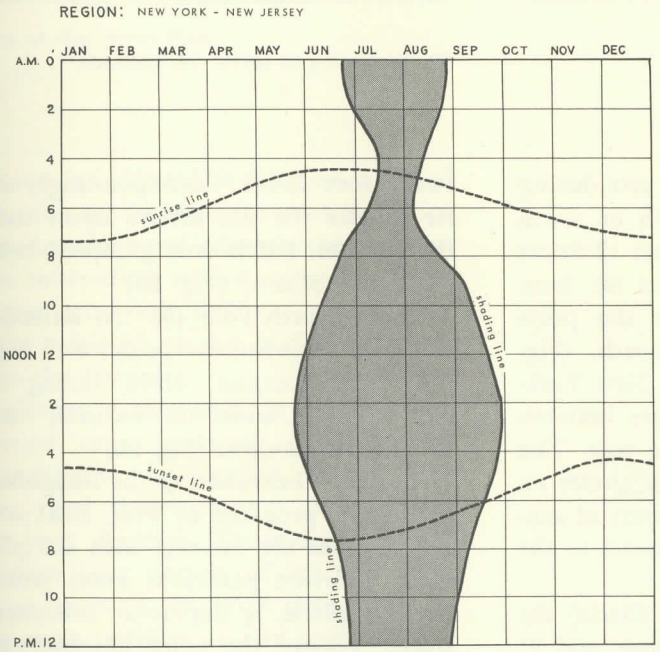
The overheated period and also the underheated (when the sun-rays are welcome) were plotted on a chart, with the months and the hours as coordinates. (Fig. 85)

A sun-path diagram can be used as a chart to plot these periods, where similarly the month and the hour lines serve as coordinates, however curved and unequally spaced they are. The diagram will then not only show the position of the sun, but indicate also whether shading is desirable or not, at a given time.

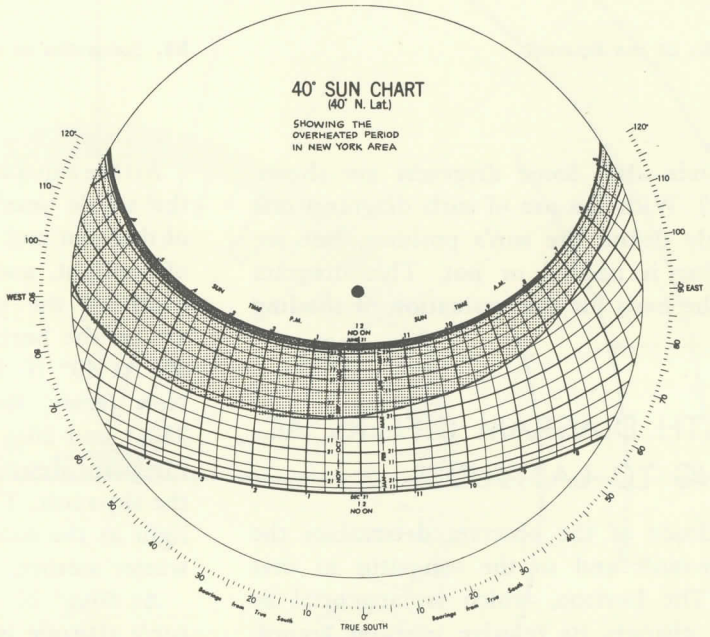
As mentioned before, by the nature of the diagram every line represents two corresponding dates, on which the sun has the same declination. Therefore, the overheated period, when plotted on this chart will look like a skin of an animal hanging on a line: some of the surfaces will overlap each other, others not. The "line" is the June 21 date-line, when the sun turns back, repeating its path.

The plotted overheated period will have areas (indicated in dark tone) to show when shading is needed on both of the corresponding dates. Other areas (indicated in lighter tone) will show when shading is needed on only one of them, which is usually the autumn date. The remainder of the diagram shows those dates on which sunshine is needed on both of the corresponding dates. (Fig. 86)

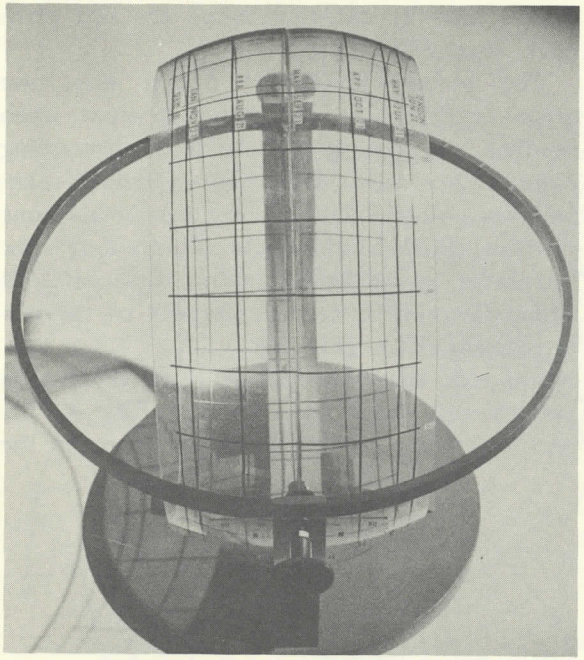
Sun-path diagrams with plotted overheated periods will differ not only according to the latitudes, but according to city or place on the



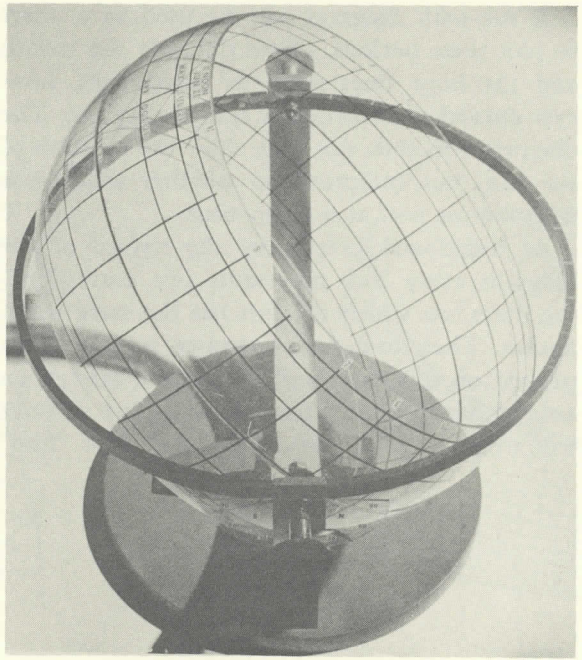
85. Yearly chart showing underheated and overheated periods in the New York-New Jersey area.



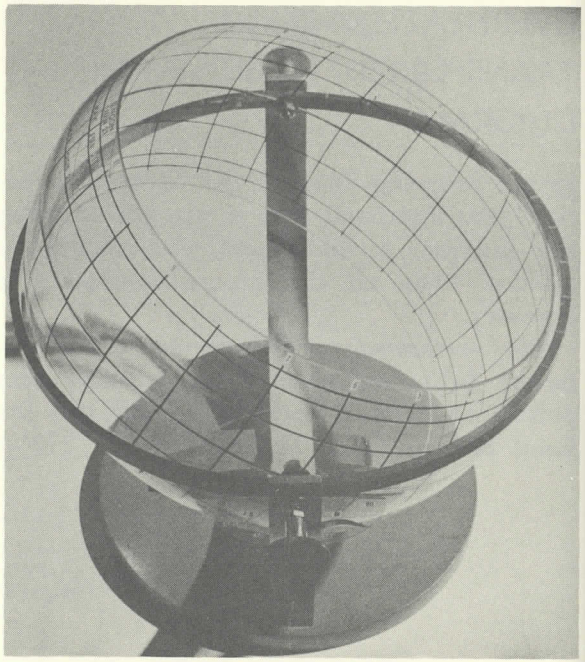
86. Sun-path diagram for the New York-New Jersey area with transferred underheated and overheated periods.



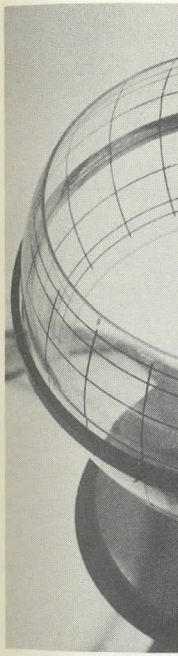
87. Sun-paths at the Equator.



88. Sun-paths at 40° N. Latitude.



89. Sun-paths at 66½° N. Latitude.



90. Sun-paths at

same latitude also. Some diagrams are shown on page 87. With the use of such diagrams one cannot only define the sun's position, but see that shading is needed or not. This diagram provides the basis for the evaluation of shading devices.

SUN-PATH DIAGRAM DIFFERS ACCORDING TO LATITUDES

The latitude of the observer determines the visible sky-vault and so the sun-paths at that location. The horizon, which is tangential to the earth, changes its relative position according to the latitudes, and therefore the visible path of the sun.

At the equator, the sun rises and sets during the whole year between 23½° north or south of due east and west. There are always 12 hours of sunlight, and the noon sun is not far from overhead the year around, because the poles are on the horizon, due north and south. (Fig. 87) At 40° N. latitude (latitude of New York-New Jersey) the sun's altitude ranges between 73½° and 26½° at noon during the year. The sun-paths describe longer and shorter circles on the sky-vault. There are almost 15 hours of sunlight at the summer solstice and 9 hours at the winter solstice. (Fig. 88)

At 66½° N. latitude (the Arctic Circle) the sun's altitude is 47° on the midsummer and 0° on the winter solstice. There is one day in the summer, when the sun is visible the entire twenty-four hours. Correspondingly at the winter solstice the sun arrives upon the plane of the horizon, but is only glimpsed briefly at the southern horizon. (Fig. 89)

At the North Pole (90° N. latitude) for half of the year the sun sweeps day and night around the entire compass, while during the winter half it circles under the horizon, leaving darkness for six months. (Fig. 90)

Another illustration of the foregoing is shown in Fig. 91, prepared by Prof. Beal which shows the angle of the sun-rays with the plane of the earth (horizon plane) at noon positions. The horizon plane is drawn as stationary, a protractor around the point of observation showing the different latitudes (0° = equator, 90° = pole); on the outside perimeter the posi-

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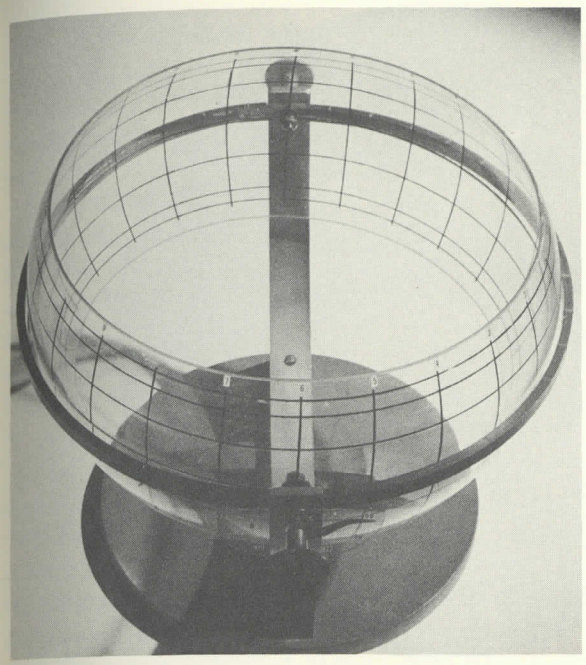
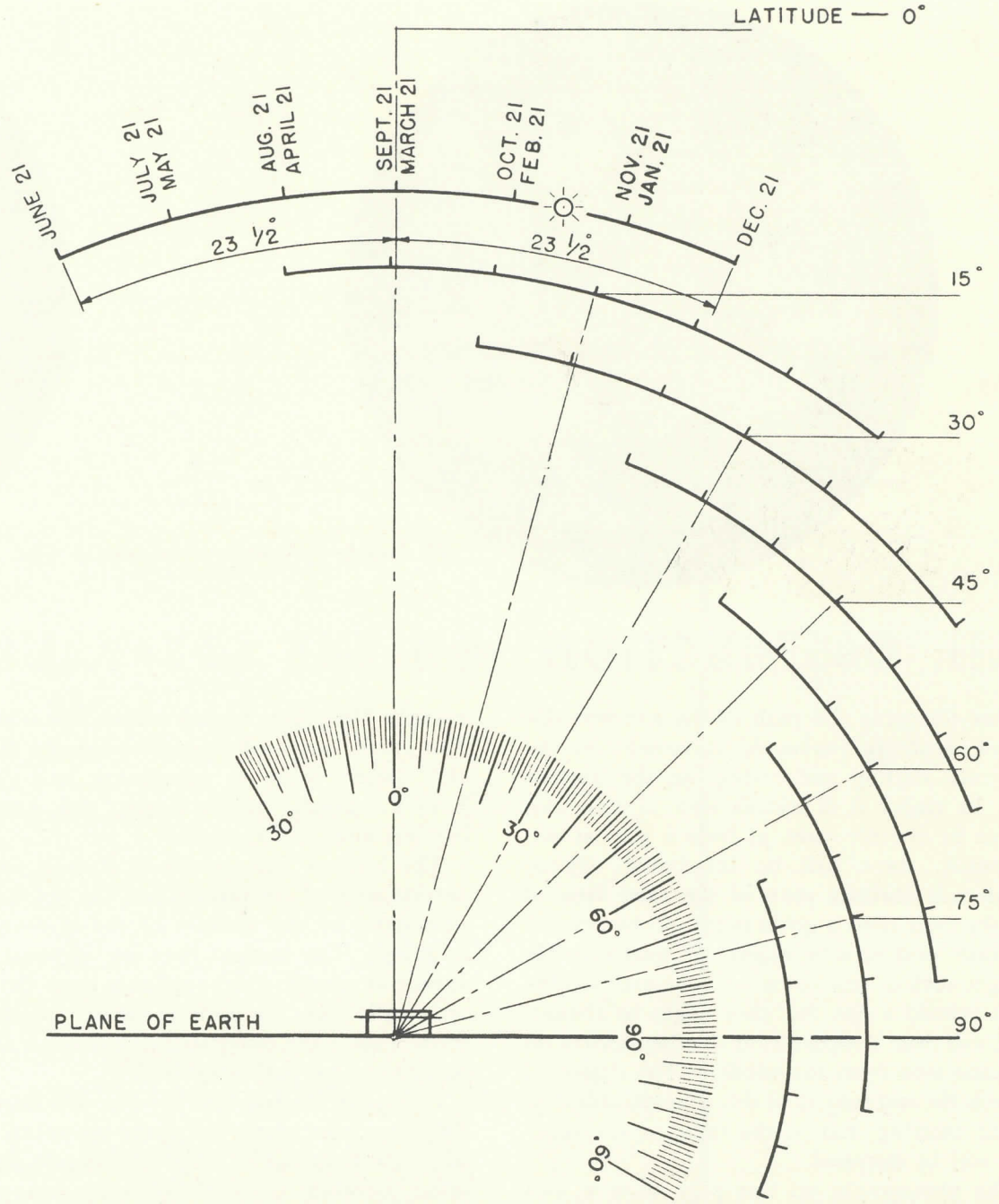


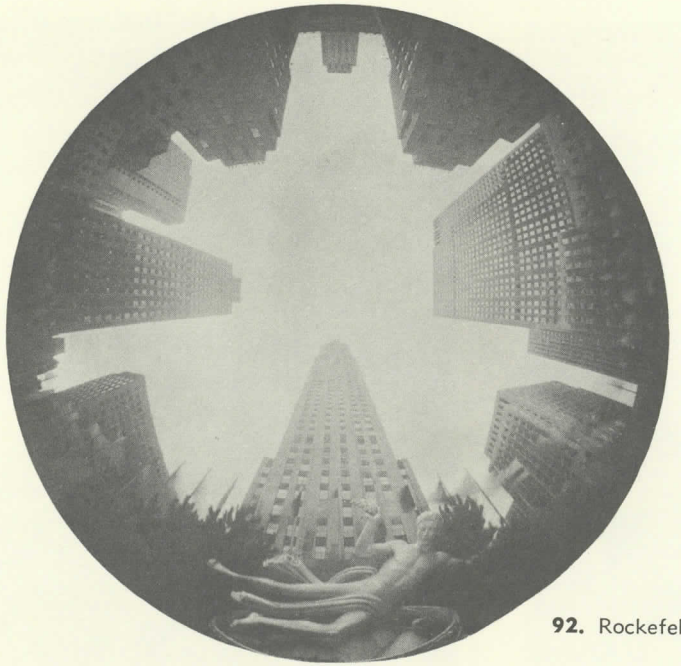
90. Sun-paths at the North Pole.

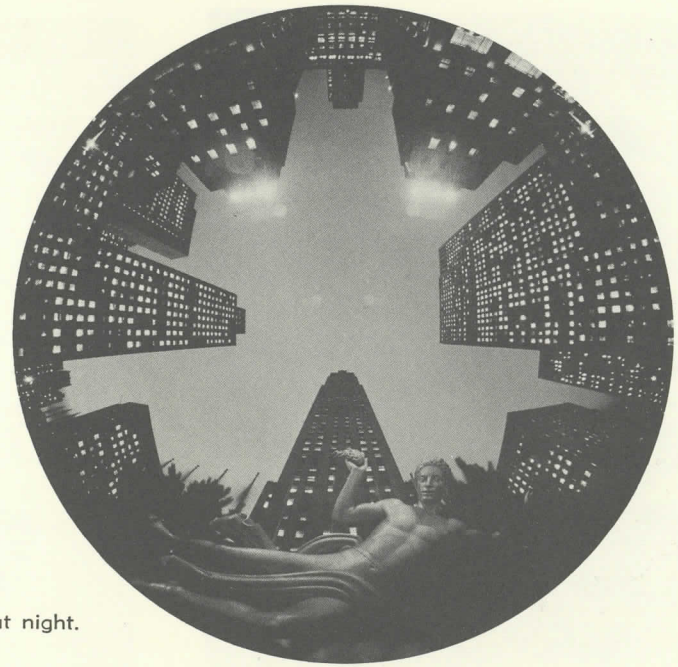
tion of the sun is indicated at different times of the year. As it can be seen, the declination of the sun remains the same (though the drawing might seem misleading at first, situating them on concentric arcs with different radii); only their relative position to the horizon changes according to the latitudes.

These different visible sections of the sun's path projected on a sun-path diagram will change according to the location (latitude) of the observer, and therefore each latitude has its own sun-path diagram. These diagrams are shown for each four degrees of latitude from 24° to 52° on pages 84, 85. With their use, one can see the sun's position at any time, or can read off the altitude and bearing angles of the sun.



91. Angle of the sunrays at noon at different latitudes.





92. Rockefeller Plaza in daytime and at night.

VIII. OBSTRUCTIONS ON THE SKY-VAULT: SHADING MASKS

IN THE foregoing the path of the sun was discussed as an uninterrupted movement on the sky-vault, starting and ending on the horizon line. In reality it is seldom seen in this way, except in extreme cases, as from a ship at sea. Generally, there will be interfering objects, which will obstruct parts of the total view of the sky-vault from a given point of observation.

These obstructions might be unchangeable objects, such as mountains or structures already built around a site. But they might be changeable, and even designable, as shading devices on a facade seen from the window. The design of these is the real subject of this chapter, although before entering into it, the topic of surroundings will be discussed.

The photographs on this page show a well known and often seen place, the Rockefeller Plaza in New York, from a seldom seen observation point. It was photographed using a Robin Hill camera with an equidistant lens system from the middle of the skating rink, once in daytime and once at night.

The horizon line appears as a circle on the outside edge of the picture and the sky-vault is obstructed by the outlines of the surrounding buildings. The vertical lines on the buildings appear as straight lines radiating from the center, while the horizontals become segmental lines. This is the characteristic distortion of the equidistant projection method.

It is quite evident, that the sun will shine on the point from where the photo was taken only when the buildings or other solid objects do not stand between them. This means, in other words, that the point of observation will receive sunshine only from those parts of the sky-vault where the sun's path is visible.

Any opaque object placed between the sun (represented by the sun-path lines) and the point of observation (the center of the diagram), will cast shadow on the latter. The same effect would occur if a light source were placed at the point of observation, thereby projecting shadows of any interfering object on the sky-vault represented by the half-sphere. These shadowed areas will be those parts of the sky-vault from which no light or sunshine will reach the point of observation. If the sun passes through such an area, the observation point will be shaded. (Fig. 93,1)

The shadowed areas from the sky-vault can be projected onto the horizon plane, in the same manner as the sun-paths, resulting in a similar circular diagram. On this diagram the shadowed

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parts of the sky-vault will appear as areas from which no sunshine will reach the point of observation (the center of the diagram). The configuration of these areas is called the "shading mask."

Such a shading mask can be plotted from any interfering object, regular or irregular in shape. Regular geometrical objects, planes or lines will have characteristic geometrical forms in their projected diagrams. Some of them, the most usual ones used in connection with buildings, are described below:

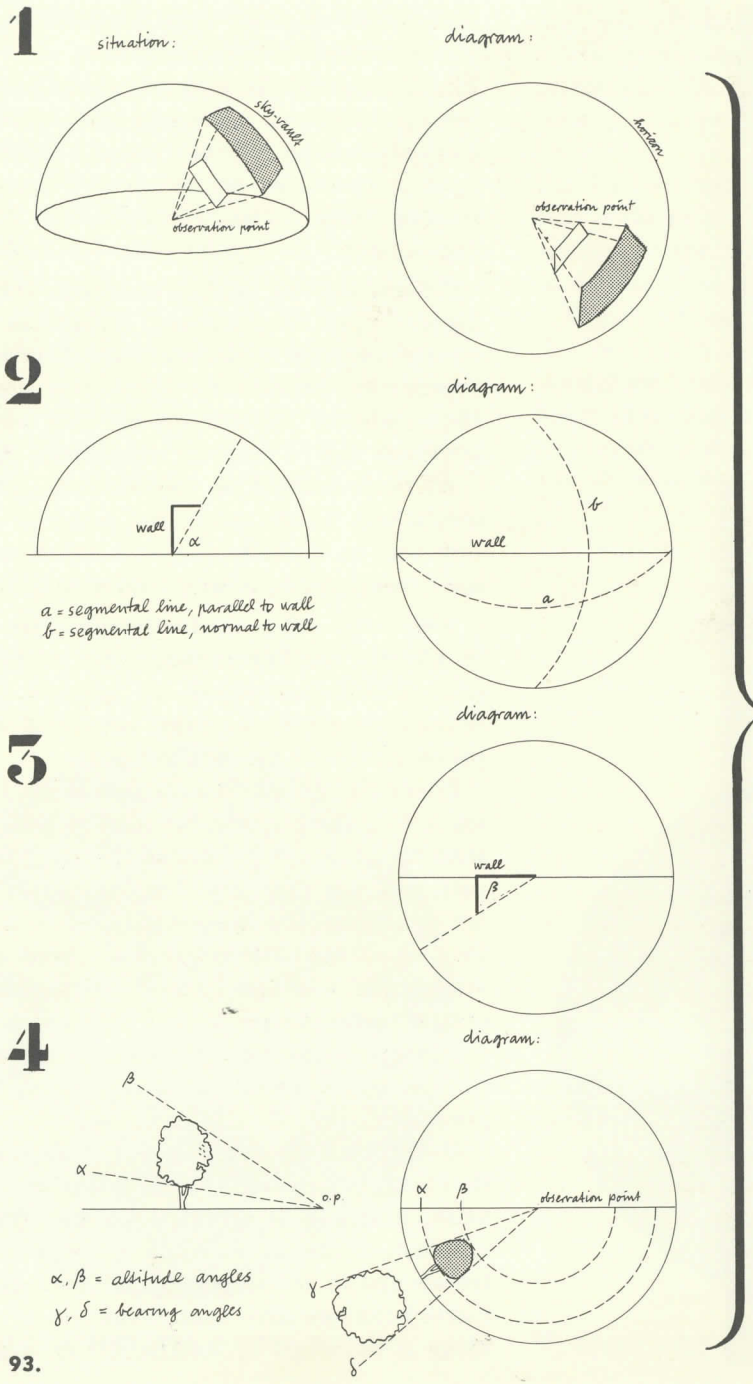
A. A horizontal edge parallel to a vertical wall (as in the case of a horizontal overhang), will show in the projection as a segmental line, which will be the projection of the intersection of the sphere and the plane determined by the horizontal line and the point of observation. The altitude angle is the angle between the horizon plane and the plane described above. (Fig. 93, 2A)

B. A horizontal edge perpendicular to the wall (as the ending of a shading device) will also show in the projection as a segmental line with similar considerations as before, but normal to the wall. (Fig. 93, 2B)

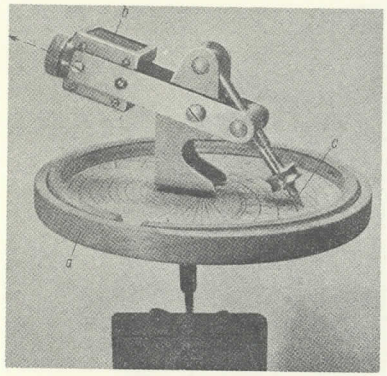
Similarly, any horizontal edge oblique to the wall can be projected on the diagram. Its segmental line will be rotated in proportion to the angle it makes with the wall.

C. A vertical edge (as in the case of a vertical fin), will show in the projection as a radial line, which will point to the center of the diagram. It is the projection of the intersection of the sphere and a vertical plane determined by the vertical edge and the point of observation. Its angle is the angle between the wall and the plane described above. (Fig. 93, 3)

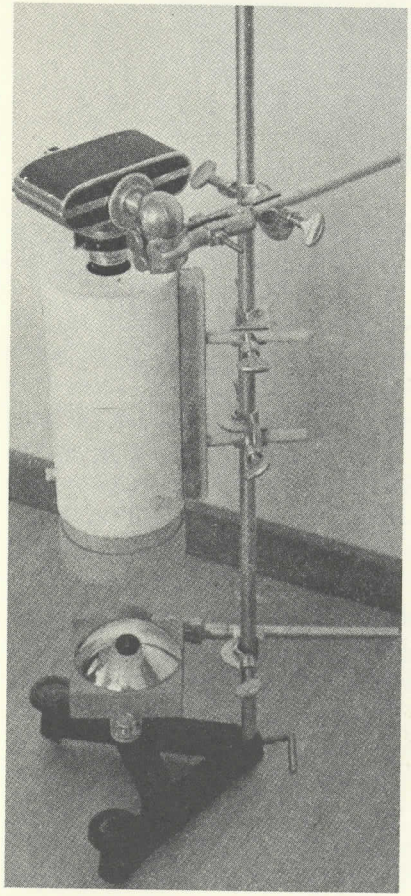
D. Outlines of window frames, or any form of external obstructions can likewise be projected on the diagram. These objects can be geometrically plotted, if their angles of bearing



93.



94. The "Horizontograph."



95. The "Globoscope."

and altitude in relation to the point of observation are known. (Fig. 93, 4)

E. A protractor, showing on one half segmental lines parallel and normal to the observed wall, and on the other half bearing and altitude lines, serves to plot any object on it, resulting in a shading mask. This protractor is shown in Fig. 93, 5.

After a shading mask is completed for a shading device, or other external obstructions, it can be superimposed on the sun-path diagram of the appropriate latitude, in the proper orientation. From this the times when the sun will be intercepted can be read off throughout the year.

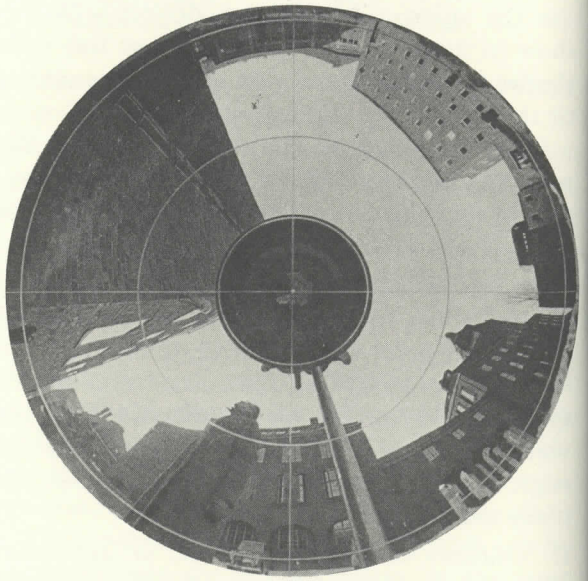
At times marked on the sun-path, which are overlapped by the mask, the point of observation will be in shade, while at times outside of the shading mask, it will receive sunshine.

There are other methods which are helpful in plotting shading masks, some photographic, some mechanical-optical. In general they are devised to record existing situations and are primarily useful for such purposes.

Friedrich Tonne[28] constructed a "Horizontograph" (Besonnungs-Schreiber) with which shading-masks can be drawn directly on a sun-path diagram (Fig. 94). The instrument is similar to a theodolite horizontally set on a tripod; the proper sun-path diagram is placed on it in accordance with the actual orientation. The optical parts (b) are moved by hand following the observed outlines of the obstructions, while the mask is recorded automatically on the diagram (c).

Other methods are based on the principle that a vaulted mirror surface will reflect the sky-vault, and this is observed by eye, or photographed. These observations or pictures can be transferred to or overlaid on sun-path diagrams. Curved mirrors have been employed in meteorology as described by Burchard,[29] or applied by Pers[30] in his "Heliopanorama Camera." This also has a spherical mirror and the purpose was to determine how much of the path of the sun was obstructed by mountains, trees or buildings. Tonne devised another instrument called "Horizontoscope," based on similar principles, with a reflective but translucent plastic paraboloid, under which the sun-path diagram can be observed by eye.

Pleijel constructed an apparatus called the "Globoscope" (Fig. 95). It consists of a paraboloidal mirror, in which, observed from above, a distorted image of the surroundings is seen in stereographic projection. The image in the globoscope can be made permanent with the use of a camera placed in the eye position (Fig. 96).



96. Globoscope photograph.

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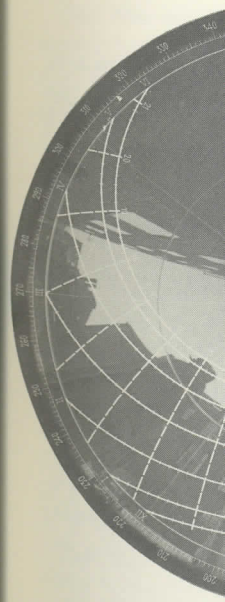

97. The globoscope
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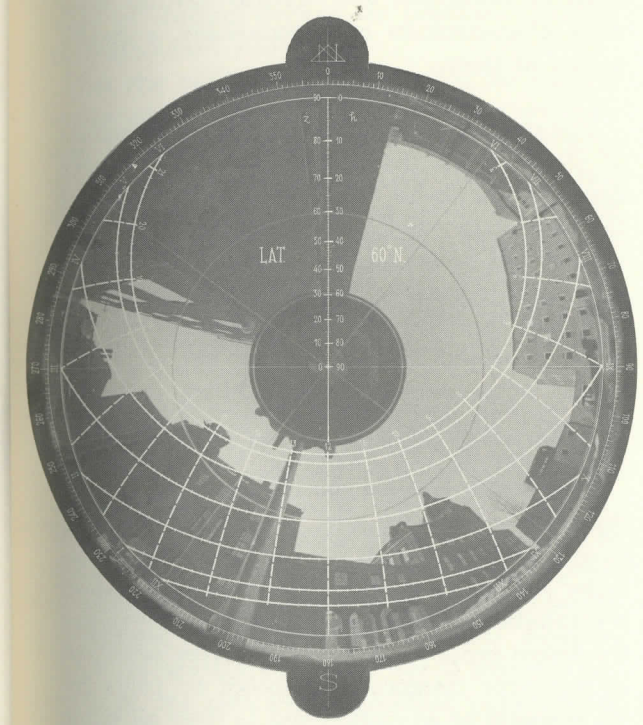
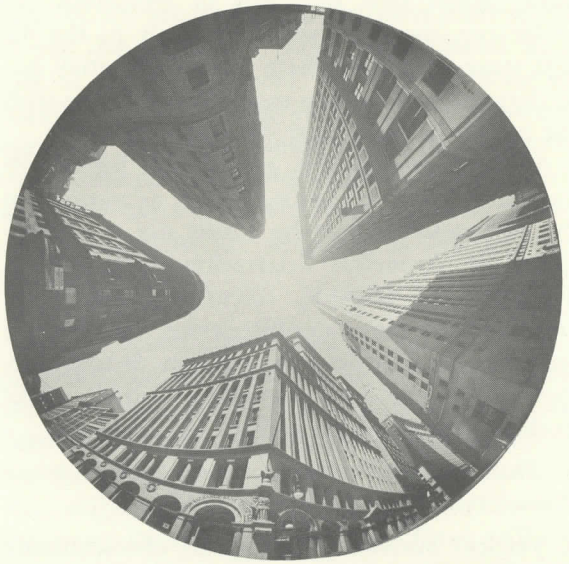
A combination picture of the mask of the surroundings and sun-path diagrams can be achieved by introducing a diagram, made on transparent material, by means of the small accessory apparatus shown in the picture. The image of the shading mask and the sun-path diagram are thus photographable simultaneously through the upper lens (Fig. 97).

Extremely wide-angle objectives are also used for the purpose of taking in the whole sky-vault in one picture. The Robin Hill camera was constructed mainly for meteorological purposes, but it can be used also for the present problem. Hill[31] devised a method of taking 180° photographs by means of a lens which contracts the incident angle of the light to about 90° before it reaches the photographic lens by which the image is projected upon the photographic plate. This is achieved by placing a portion of a glass sphere with its center directed at the pinhole, where a positive lens is introduced to project the image upon the plate. With this arrangement various distorted images of the sky-vault can be photographed, which will be measurable, provided the angles to the axis made by any ray outside (called ϕ) and inside the camera (called θ) have a ratio, where the tangents of ϕ and θ shall be constant. The two most satisfactory ways of projecting a hemisphere onto a plane are by the stereographic projection in which the ratio $\phi/2$ to tan θ is constant, and the equidistant projection in which the ratio ϕ to tan θ is constant. A less satisfactory method is the orthographic projection in which the ratio sin ϕ to tan θ is constant. It has been found by use of the Hill camera[32] that the equidistant projection is the most satisfactory and easily employed method of the three; this same method is used in the diagrams of this study.

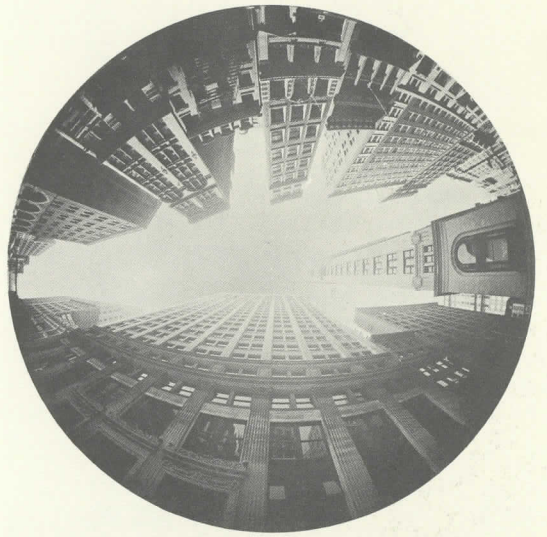
Figures 98 and 99 show pictures taken with this camera in equidistant projection in downtown New York. Besides being shading mask illustrations, they can serve also as shocking examples for town-planners to see how little sun a downtown New Yorker receives.



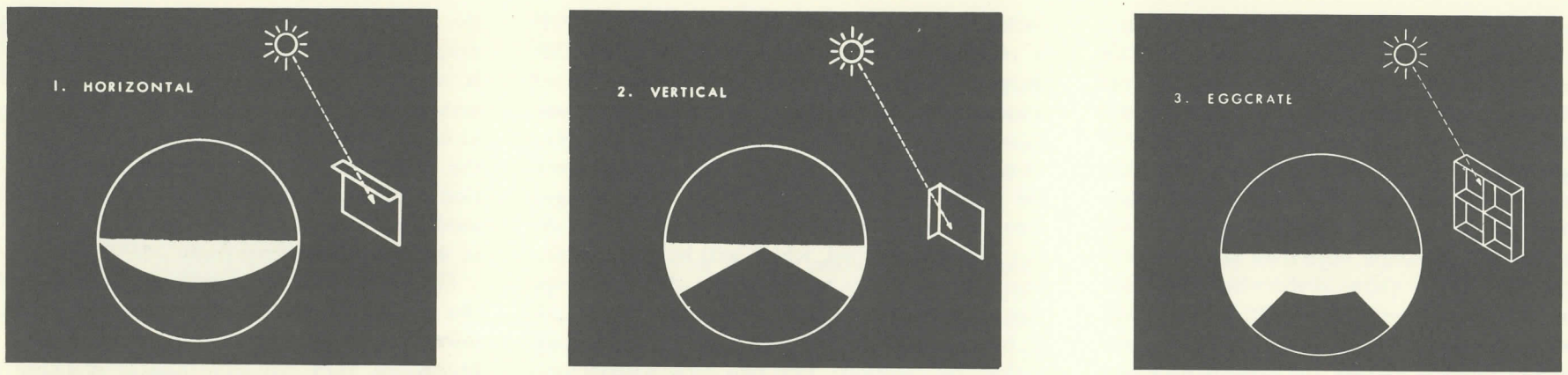
97. The globoscope photo combined with sun-path diagram for 60° N. latitude.



98. Equidistant photo of downtown New York City.



99. Equidistant photo at Maiden Lane, New York City.



100. Scheme of horizontal, vertical, and eggcrate devices.

The preceding methods are usable to obtain shading masks by various instruments. All these methods are applicable, though only in cases when already existing situations are under investigation: that is, areas or buildings already built. When new buildings or elevations are under consideration, which are only in the design stage on paper, there is no alternative but to draw up the shading mask geometrically with the use of the protractor (Fig. 93, 5).

As mentioned before, geometrical forms will have characteristic shading masks, as plotted on the protractor. Since the masks are a conventionalized geometric description, they are independent of latitude, orientation and time. Once plotted for a specific device, the shading mask can be used in any situation. Shading devices can be tabulated according to their masks in three main categories (Figs. 100, 101):

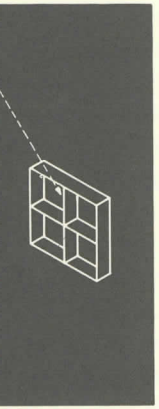
A. Horizontal overhangs: their typical mask characteristics are the segmental lines.

B. Vertical louvers: their typical characteristics are the radial lines.

C. Eggcrate types: they are basically combinations of horizontal and vertical devices; their mask characteristics are, accordingly, a combination of these.

The characteristics of shading are independent of the scale of the device. The ratio of the depth of the device to the proper dimension of the wall surface is the determining factor. This is expressed by the angle, which shows this ratio in a plane normal to the wall. The shading effect, and therefore the mask, depends on this angle. A very small-scaled device, like the "coolshade" or an outside venetian blind, will have the same shading mask as a balconied apartment house if their angles are the same.

This makes possible the tabulation of devices different in form or size, into the above-mentioned three categories, according to their similarity in shading masks. With this categorization a vocabulary of shading masks can be developed for design purposes. Some of the types tabulated in the three categories are shown on pages 88-92. It would be an endless task to show all types, but this table illustrates the various characteristics of typical devices. Many further combina-



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tions of shading devices are possible, resulting in combinative masks.

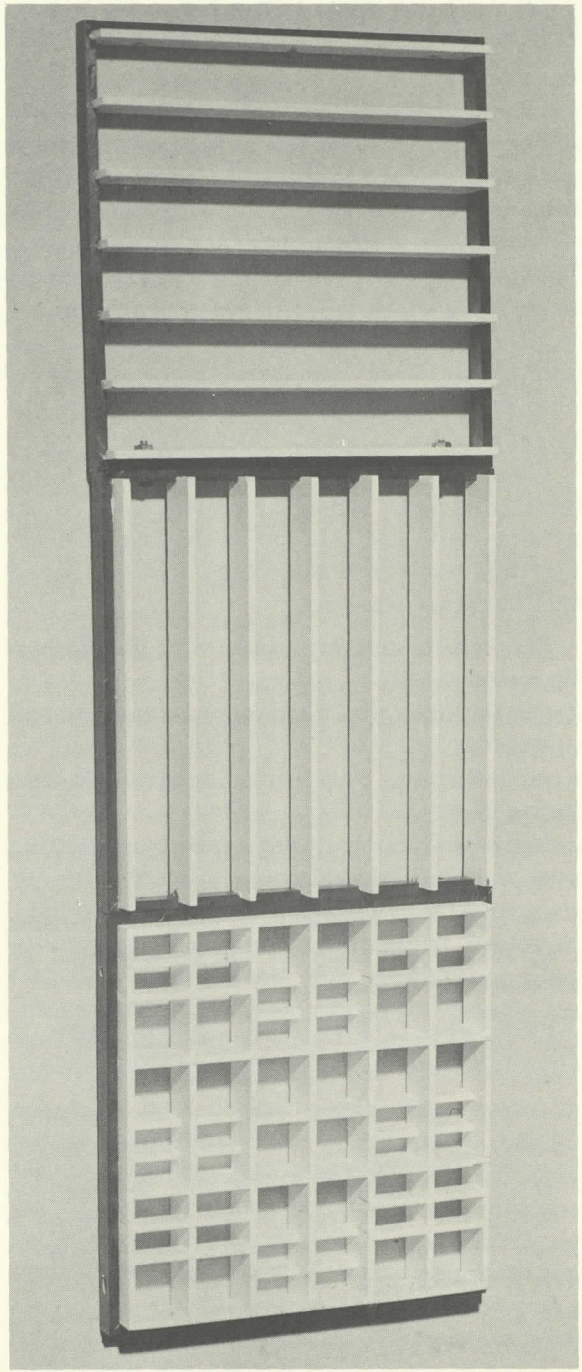
For the evaluation of a shading device two masks can be shown: one for 100 percent shading, in which case the total wall surface is in shade, and one for 50 percent shading, when only the half of the surface is in shade. The masks accordingly show the 100 percent and 50 percent shading diagrams. The system of using these masks is amply illustrated in the architectural examples, shown in the last part of the book.

The mask of a shading device with its 100 percent and 50 percent diagram superimposed on the sun-path diagram with the plotted overheated period will show the times when the sun will be intercepted by this device. The process can now be reversed for design purposes. A suitable shading mask can be drawn from the overheated period on the sun-path diagram. This shading mask should cover as much as possible of the indicated overheated period while at the same time taking care not to cover too much of the underheated period when sunshine is needed.

Having determined the shading mask, a particular shading device can then be designed. In Chapter XV, an example shows how this can be done in practice.

The effectiveness of any such device will depend on the relation of sun intensity intercepted during the overheated period as compared with that of the underheated period. As a rule of thumb, it can be said that if the 50 percent border of the shading mask covers the indicated overheated periods, the shading device will work well. For accurate evaluation, however, radiation calculations are necessary as described in Chapter XII.

As mentioned above, with the use of the sun-path diagram with the overheated period plotted on it, the proper overlapping mask can be determined and an appropriate shading device for the situation developed. Since various devices might have the same mask and therefore the same shading characteristic, there will be many technically correct solutions for each situation. To choose between them is the designer's task. Here the domain of creative design starts.



101.

IX. DAYLIGHT ILLUMINATION

A SHADING device will, as will any interfering object or obstruction, cut out parts from the visible surface of the sky-vault. From these parts, defined by the shading mask, no light from the sky-vault will arrive at the observation point. Thus a device will influence the amount of entering light, which is sometimes desirable in case of glare, but it may reduce the illumination excessively. It is of interest to know, therefore, what percentage of the sky radiation is cut out by each device.

This can be computed and a ratio set up, between the light amount entering through an opening with and without a shading device.[33] This will result in a percentage, which is called here daylight "efficiency."

The calculations are made with the following assumptions:

A. the sky has equal luminance of radiation at all points.

B. no reflections from surroundings or louvers are received.

C. louvers are so long that the light entering from ends can be neglected.

1. For horizontal overhangs or horizontal louvers (Fig. 102A,B) the efficiency can be expressed by the following equation:

$$\text{Efficiency} = [\sqrt{1 + (c/h)^2} - (c/h)] \cdot 100\%$$

This results in the following numerical values:

c/h	Efficiency %	c/h	Efficiency %
0	100.0	0.6	56.5
0.1	90.5	0.7	52.0
0.2	81.9	0.8	48.0
0.3	74.3	0.9	44.4
0.4	67.6	1.0	41.4
0.5	61.7	2.0	23.6

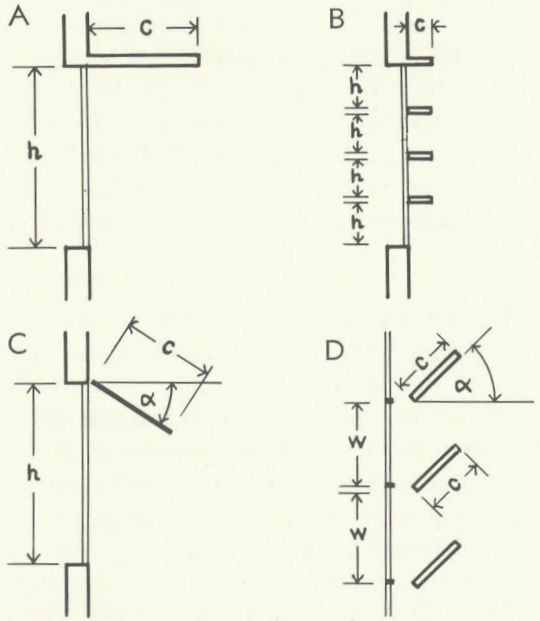
2. For tilted horizontal overhangs or louvers (Fig. 102,C) the efficiency can be expressed as:

$$\text{Efficiency} = [\sqrt{1 - 2\,(c/h)\sin\alpha + (c/h)^2} - (c/h)\cos\alpha] \cdot 100\%$$

3. For vertical fins, perpendicular to the elevation or tilted (Fig. 102, D) the efficiency is:

$$\text{Efficiency} = \tfrac{1}{2}[\sqrt{1 - 2\,(c/w)\sin\alpha + (c/w)^2} - \sqrt{1 + 2\,(c/w)\sin\alpha + (c/w)^2} - (c/w)] \cdot 100\%$$

As most of the eggcrate devices can be analyzed as combinations of horizontal and vertical types, the above equations can be used in their efficiency calculations. Nevertheless, they might become very lengthy in some more complex types. Furthermore, in case of irregular obstructions, as often occurs in surrounding objects, the calculative method is impracticable.



102.

Graphical methods can be used also to determine the daylight efficiency of a device.

The shading mask will define the parts of the sky-vault from which light is received. It is possible to construct a diagram on which the overcast-sky radiation is represented in the same projection method. Overlaying this diagram on to the shading mask, the amount of light entering on the uncovered areas can be read off.

Pleijel made extensive studies in this field,[34] constructing nomograms of the luminance of the sky. In these, uniformity of the sky radiation over the whole sky-vault and no reflections from the surroundings were assumed.

Here, a circular nomogram is obtained by projecting the equally-illuminated sky-vault onto the circular horizon plane, divided into squares by means of a network, with an area of every square as 1/1000th part of that of the circle. Each square is represented by its geometrical midpoint, which also is the centroid of the radiation. The midpoints are then projected perpendicularly from the horizon plane up on the surface of the sky-vault. They are then projected again onto the horizon plane by stereographic projection. This results in a nomogram with points indicating the centroids of the radiation units. These points are equivalent, each representing 1/1000th part of the radiation factor of the whole sky-vault.

In use, a shading mask is laid on the nomogram and the number of points are counted which fall on the sky of the diagram not covered by the mask. The number of points is divided by 1,000 to obtain the radiation factor. To facilitate the calculation the points have been collected together into groups of 25.

Figure 103 shows the same globoscope picture from Pleijel, which was shown on page 47, but combined now with the sky radiation nomogram. The number of points which can be counted on the unobstructed part of the surface

103. Globoscope nomogram.

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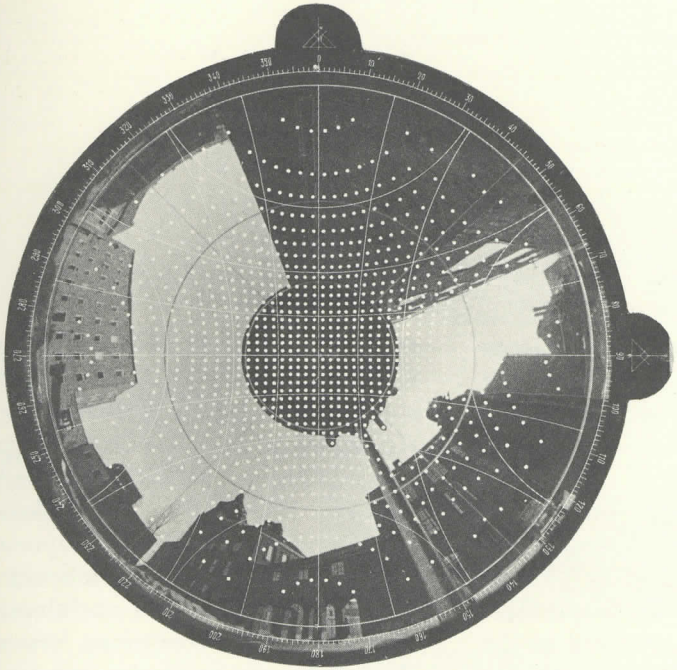
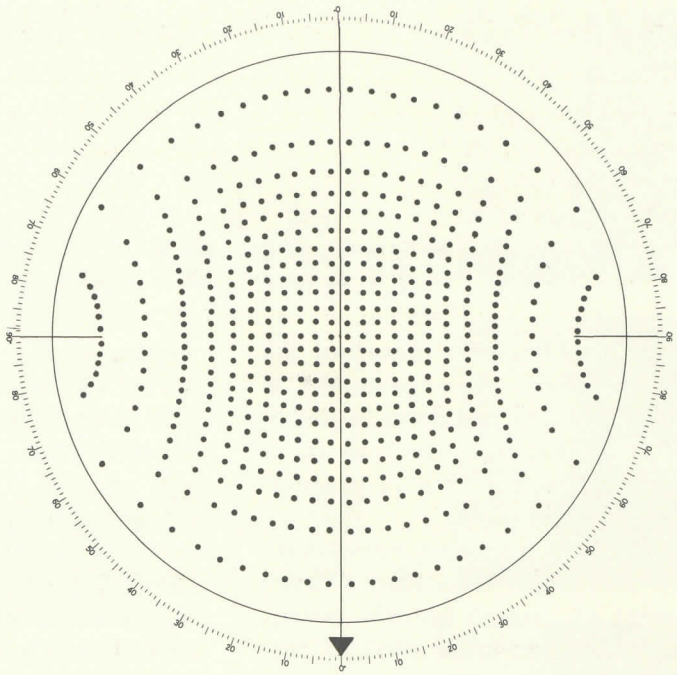


103. Globoscope photo combined with sky radiation nomogram.



104. Sky radiation nomogram in equidistant projection. One point equals 1/500th of the total sky luminance.

of the sky is 634. This figure divided by the total number of points (1,000) results in the radiation factor, which in this case is 0.63.

A sky radiation nomogram, showing the radiation factor for a vertical or any oblique surface, can be obtained in similar fashion. The sky-vault intersects a vertical plane also in a circle. The upper half of this is divided with a network similar to that used for the horizontal plane. The methods of construction and radiation factor calculation are similar to the one above.

Using the graphical method in the equidistant projection, in which all other diagrams of this study were made, Fig. 104 shows the sky radiation nomogram for horizontal surfaces. Here the total number of points is 500, which is easily applied to all internationally used total sky-illumination units (5,000 lux, 465 ft.-candles or 100 daylight units). The horizon circle is divided into 500 parts of equal area, but with different configurations. The net of divisions was laid out with uniformly distanced ellipses in one direction and differently spaced straight lines in the other. The advantage of this subdivision is that any ellipse projected on the sky-vault defines a great circle there, which can be interpreted as an intersection of the sky-vault and a plane. This is the same geometrical situation as when the shading mask of a horizontal device is constructed; thus the projection of these great circle lines will coincide with those of the horizontal shading masks. The points, which represent equivalent centroids of the radiation units, therefore will show the same segmental character, which will facilitate their readings. The nomogram can be used as an overlay on a shading mask with the same procedure as described before, resulting in the sky radiation factor.

These nomograms were constructed with the assumption that the sky has equal density of radiation at all points. This is assumed in most illumination calculation methods, though this simplification agrees only approximately with the truth. Measurements show that the luminance, or light density of the overcast sky, increases from the horizon to the zenith. It is not intended to enter into this topic, which is mentioned only to point out that nomograms can be constructed for unequally distributed sky luminance. The density of the points on the nomogram can be adjusted so that they would be closer together around the center and more sparse near the horizon.

X. SHADING EFFECT OF TREES AND VEGETATION

THE ancient Chinese philosophers described the protecting effects of trees; the relationship of building and landscape was laid down in principles such as the "pei-shan-mien-shui," an intuitive knowledge which is the fruit of practical experience over the generations.

The old custom of surrounding homes with embracing trees has deeper roots than a desire for the enjoyment of nature's esthetic variety. Besides satisfying the instinctive need of protection, trees also perform many services to better man's immediate physical environment.

Trees and shrubs, if densely planted, reduce air-borne sounds with great efficiency. The viscous surface of leaves catches the dust and filters the air. Vegetation can also secure visual privacy, and reduce annoying glare effects. But a very beneficial effect of trees is their thermal performance. In wintertime evergreen wind-breaks reduce the heat loss from buildings and discourage drifting snow. In summer the grass surfaces and leaves absorb the radiation and the evaporation process cools air temperatures. Above all they provide generous shade at exactly the appropriate seasons. This fact makes deciduous trees especially valuable when placed close to buildings.

One aim in solar control is not to interfere with the winter sunshine. This rules out evergreen trees placed near buildings and gives practical preference to those trees which gradually clothe their branches with leaves as the warmer weather approaches, are in full bloom during hot summer days, and toward autumn thin their foliage so that the sun can easily penetrate their leafless branches during the cool periods.

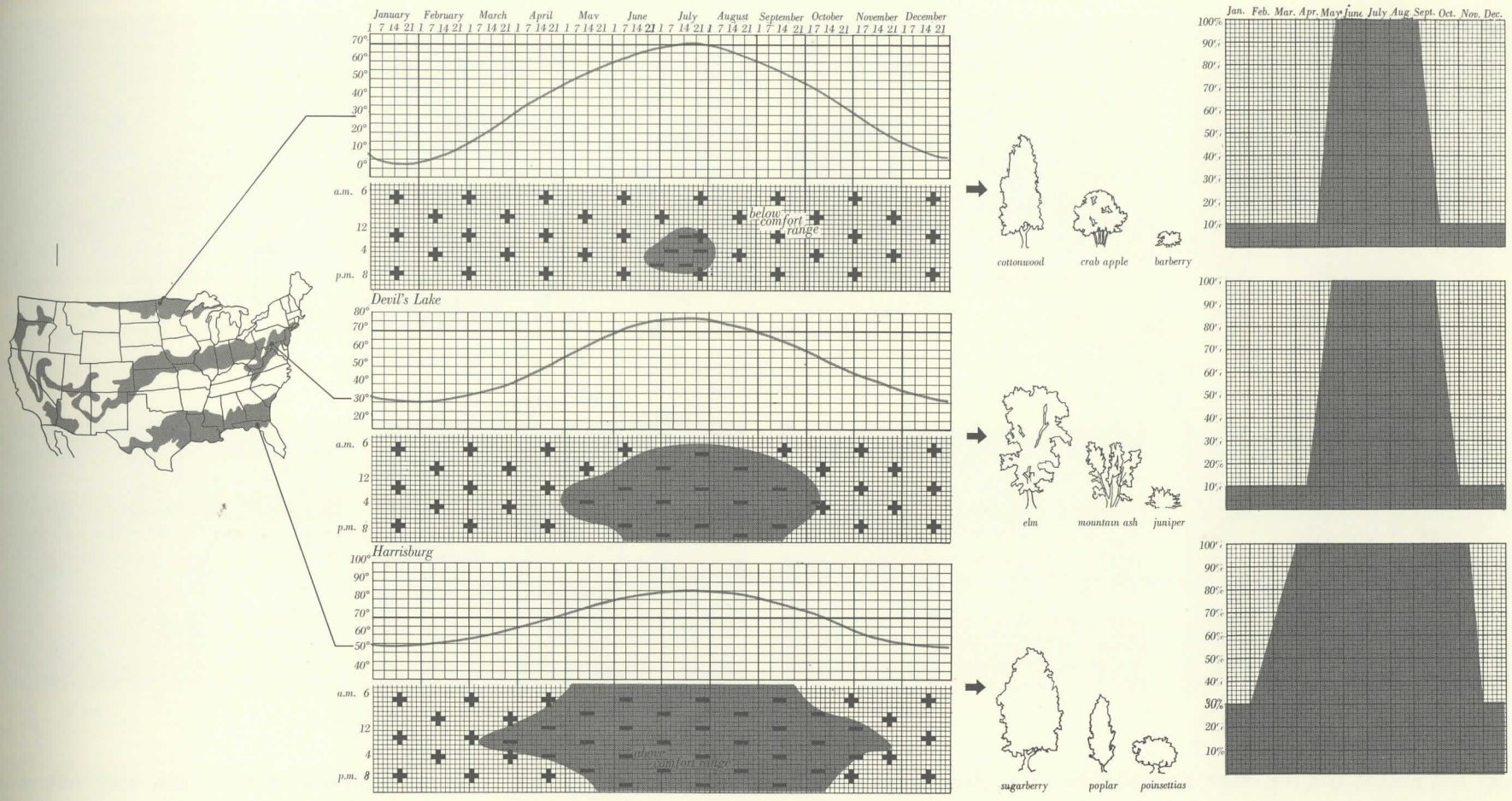
Figure 105 charts the yearly temperature variations of three locations in the United States: Devils Lake, N.D.; Harrisburg, Pa.; and Pensacola, Fla. Charted under the yearly temperature curve for each of these cities is a record of the 24 hours of the average day for each month. On this the overheated period, when shade is needed, is outlined in darker tone. On the right-hand side trees and shrubs are indicated which are native to the given locations. On the far right the shading period of the trees is shown on a chart where the vertical scale indicates the percentage of shade which occurs in months designated on the horizontal scale.

It seems evident from this chart that although in each case the leaves arrive on the branches of these trees somewhat early for shading, the time of the full bloom period and of the shading needs in the given areas correspond very closely. They cooperate elastically with human needs even in their seasons. In cold spring the leaves arrive later, in warm summer last longer—within a variation of six weeks.

Vines constitute another of nature's automatic heat-controlling devices: cooling by controlling evaporation and providing shade. This combination makes it well suited for sunny walls in hot weather. Here are some recommended vines:[35] Clematis, Celastrus scandens (Bittersweet), Vitis riparia (Frost Grape, River Bank Grape, etc.), Parthenocissus, Hydrangea petiolaris, Wistaria (Wisteria), Silver Lace Vine, Chinese Fleece Vine, Clematis paniculata, Dutchman's Pipe, Forsythia, Ipomoea.

Trees, also, should be selected according to their attractiveness and usefulness for shading. Climatic and soil conditions, however, should be checked for the particular area under consideration. Some of the trees recommended for shade purposes are: Populus sp. (Poplar), Acer saccarinum L. (Silver Maple), Acer saccharum Marsh (Sugar Maple), Acer schwedleri (Schwedler Maple), Betula papyrifera Marsh (White Birch), Gleditsia Triacanthus inermis (Moraine Locust), Ginkgo biloba (Ginkgo Tree), Sorbus L. (Mountain Ash), Tilia americana L. (Basswood or Linden), Malus coronaria L. Mill (Siberian Crab Apple), Fraxinus americana L. (White Ash), Quercus sp. (Oaks), Platanus acerifolia (London Plane Tree), Platanus orientalis (Oriental Plane Tree), Elaeagnus angustifolia (Russian Olive), Cornus florida (Flowering Dogwood), Liquidambar styraciflua (Sweet-Gum), Fagus grandifolia (American Beech), Celtis laevigata (Sugar Hackberry), Cercidiphyllum japonicum (Katsura Tree), Magnolia acuminata (Cucumber Tree), Salix babylonica (Weeping Willow).

It is desirable to transplant shade trees in as

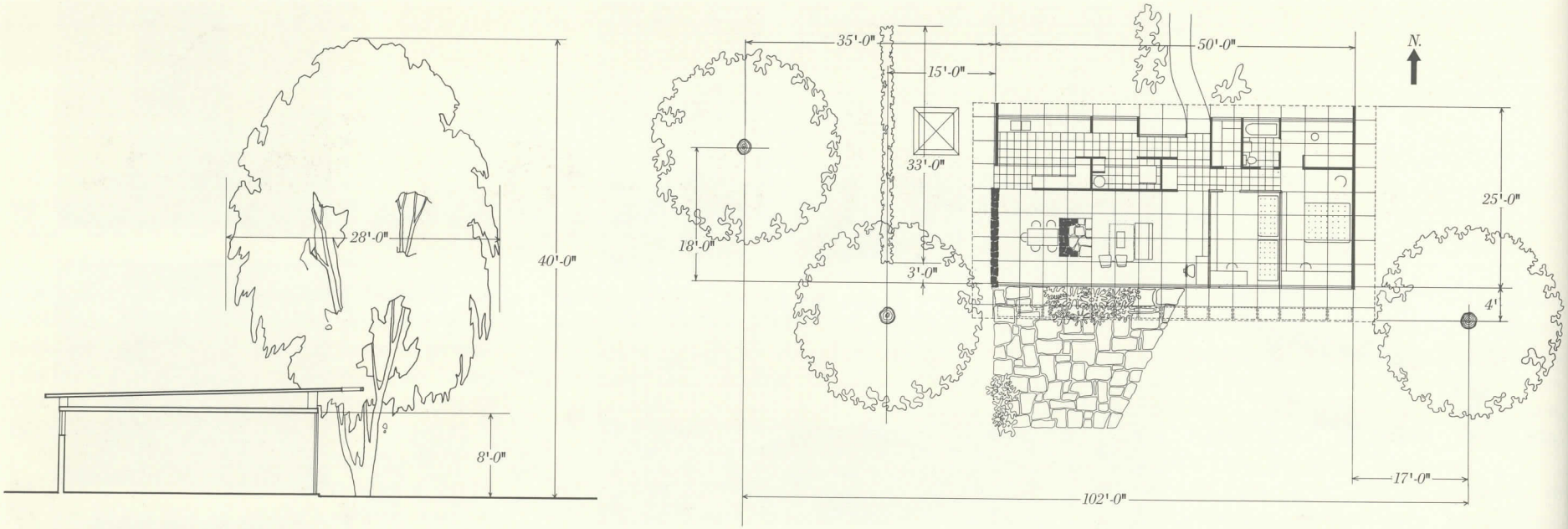


105. Yearly temperature variations in three locations in the United States with shading periods of native trees.

large a size as practicable. Certainly, for a tree to give results in a comparatively few years it should be planted in the fifteen- to twenty-foot heights. It does, however, not take some trees as long to mature to their full usefulness as is often assumed; generally when a fast-growing five-year tree is planted, it takes only five more years to grow to 80% of its full shading effect.

To achieve efficient shading, trees have to be placed strategically. As the sun passes in the morning and late afternoon at a low altitude angle, trees give their best performance on the east, south-east and on west, south-west side. Low sun-rays cast long shadows, which can be utilized effectively on those sides otherwise difficult to protect from the sun's heat. At midday the sun's path is high and the rays can be intercepted easily with an overhang; at this time of day the trees on the south side perform poorly, casting their shadows near themselves.

In considering this matter, the choice of tree to be utilized in a given location is very important. One must keep in mind two things: the shape and character of the tree itself both in



106-107. Section and plan of a house showing the location of vegetation and overhang measurement.

summer and winter, and the shape of its shadow which will be effective as a natural shading device. The first perhaps demands an esthetic judgment, the second requires a calculated answer.

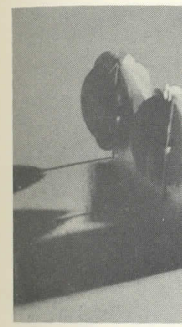
Among the deciduous shade trees[36] the maple and ash produce more or less circular shadow effects during the summer, with an ascending branch pattern in winter. The linden is spherical too, but is dense and twiggy without its leaves. The honey locust and tulip tree have oblong shapes. Wide and horizontally oblong is the white oak with an open branched structure in winter. The lombardy poplar is columnar in appearance, and the American elm vase-shaped.

Among the small flowering trees one can find a great variety of forms, such as the upright growing crab apple, the dogwood with its horizontal branches, the vase-shaped honeysuckle, the rounded spirea, the columnar enkiathus, or the broad spreading dwarf Japanese quince.

Each of these shapes has a definite implication in its shading effect. The exact location of trees and vegetation can be determined with its shading mask through the use of the protractor described in Chapter VIII.

The projected mask of the trees should cover the outlined overheated period.

The plan on the page shows such an evaluated arrangement in the temperate climate area. Here the early morning sun may relieve the coolness of the daybreak. After 8 A.M. the east side gets protection from the single tree at the southeast corner. At noon an overhang shields the building. In the early afternoon the tree on the southwest corner protects the west side. For complete shade coverage there is another tree to the west. This is placed at a greater distance from the house, as the setting sun lengthens the shadows. The west hedge is intended to catch the last low-angle evening rays. The photographs of a model on the opposite page show how these trees will cast their shadows during the consecutive hours of a summer day from dawn to dusk.



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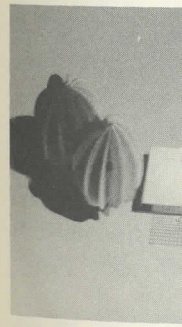

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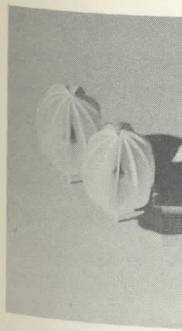

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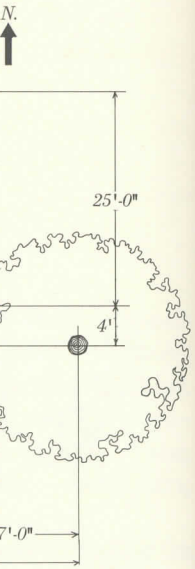

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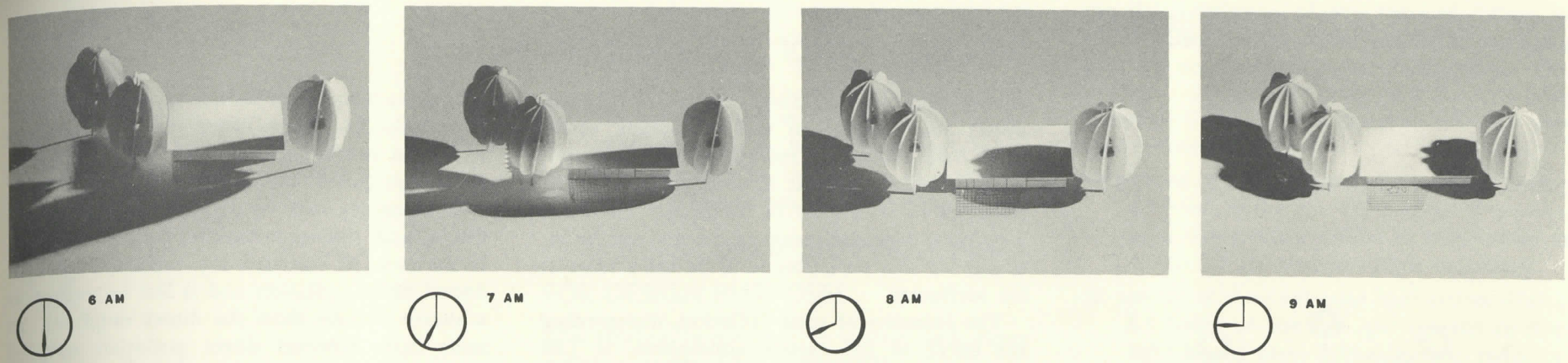
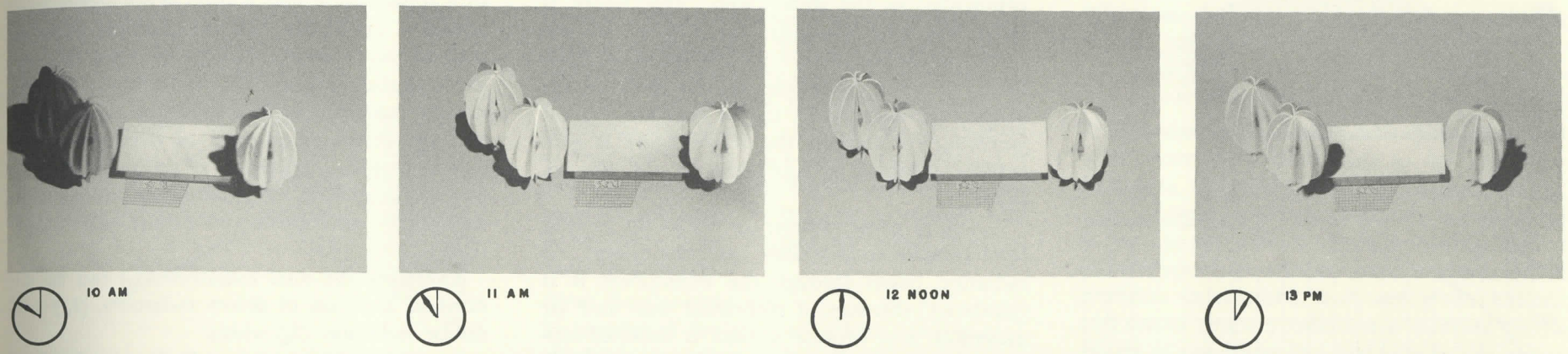
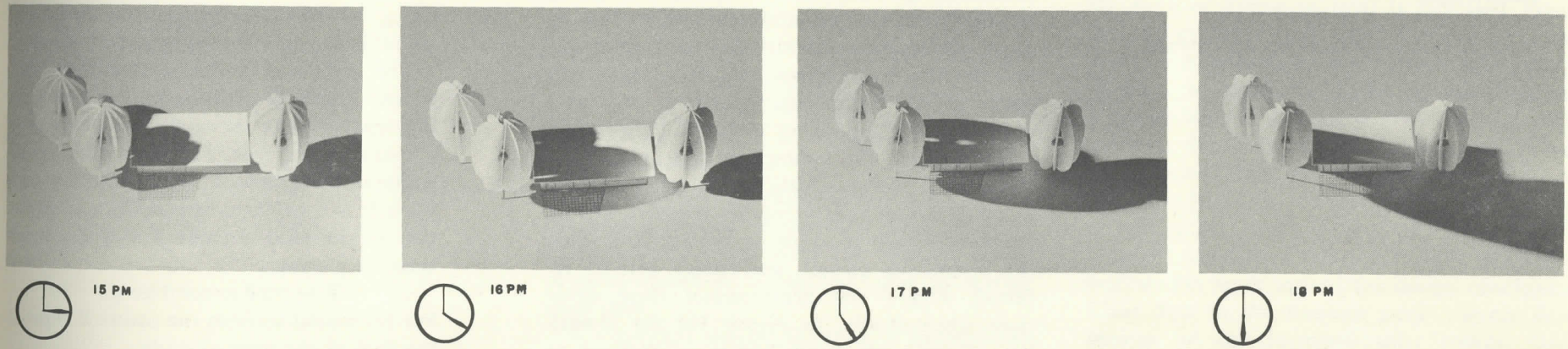
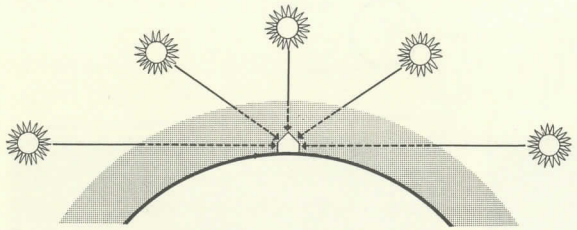




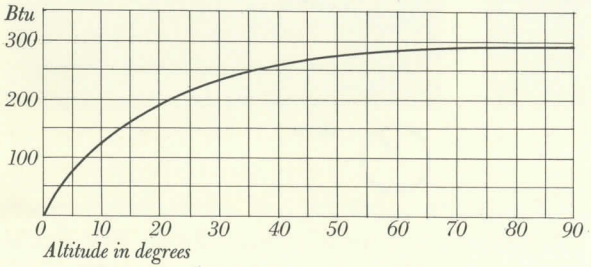


108. Summer shading from dawn to dusk.

XI. SOLAR ENERGY



109. The path of sunbeams through the atmosphere.



110. Solar energy in relation to the sun's altitude.

CALCULATION OF SOLAR RADIATION

PRACTICALLY all the energy that produces variations and motions in the atmosphere comes to us from the sun as radiation. Solar radiation is also one of the most important natural contributors to heat gain in dwellings. Therefore a quick and precise means of calculating the intensity of this radiation is of primary interest for architects.

The intensity of solar radiation, disregarding the effect of the earth's atmosphere, is 1.94 cal/cm²/min, measured on a plane surface perpendicular to the solar beam. This figure is called the solar constant and is based on the earth's mean distance of 93 million miles from the sun. Slight variations in the sun's energy output are disregarded in the constant. In engineering calculations the above figure is generally considered as equivalent to 420 Btu/sq. ft./hr.

A similar perpendicular surface at the ground level receives considerably less solar energy. As radiation passes through the atmosphere it is "scattered"—because of suspended dust and air molecules and because a part is reflected diffusely from the clouds back to space. Before it reaches the ground, solar radiation is reduced by impurities in the air and partly absorbed by some atmospheric constituents, especially carbon dioxide, water vapor and, at upper levels, ozone. Thus the transmitted energy will vary according to the distance the sun's beams must travel through the atmosphere. At noon when the sun is nearest vertical and the distance shortest, the amount of energy received will be greatest. In early morning or late evening, when the distance is greater, less energy will be received. Figure 109 demonstrates these situations schematically. In Figure 110 the intensities of the sun's direct energy as received at normal incidence are indicated with respect to solar attitudes. These values are representative of a clear summer day at sea-level according to Moon's proposed standard.[37]

Solar energy may be divided into two types; direct, and diffuse radiation. Diffuse radiation is the sum of scattered sky radiation and reflected direct radiation and is less important as a source of heat than the direct radiation. In some cases reflected direct radiation coupled with long-wave terrestrial radiation can amount to a considerable heat source. This occurs near reflective or highly emissive surfaces such as sand or paved areas, resulting in a flux of heat to the building. However, under usual circumstances the order of magnitude of this heating and the restricted interval of occurrence precludes long-wave radiation as an important factor. Consequently, the following calculations deal solely with direct and diffuse solar radiation.

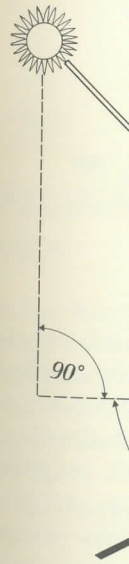
Therefore the total radiation (I_t) can be defined as the sum of direct radiation (I_D) and diffuse radiation (I_d) where

I_t = total incident solar radiation in Btu/hr./sq. ft.

$I_D = K \times I_{Dn}$, where I_{Dn} designates the direct solar radiation to a receiving surface normal to the sun's rays expressed in Btu/hr./sq. ft. and where K = cosine of the angle of incidence θ. Since the angle of incidence is a spatial angle (Fig. 111) it is difficult to define in some cases. Therefore, for vertical walls it is usual to substitute K as a function of the solar altitude β and the solar azimuth γ, thus

$$K = \cos\theta = \cos\beta \cos\gamma .$$

For horizontal surfaces the cosine K equals the sine of the solar altitude.



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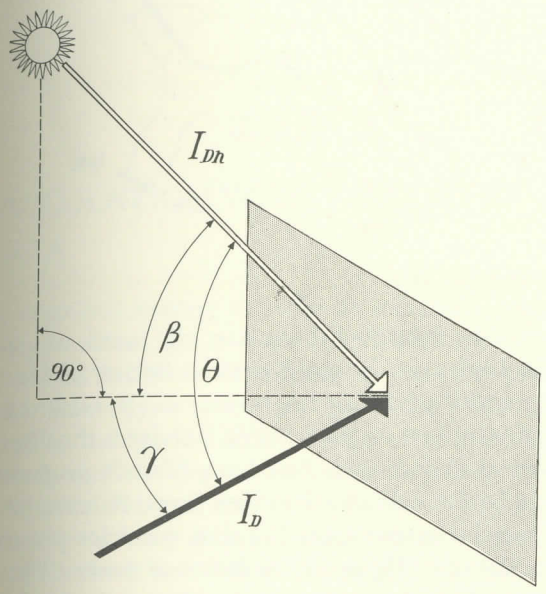


111. The angle of incidence for direct radiation.

I_d = the diffuse sky radiation. As described before, this is principally a consequence of scattering caused by the atmosphere. A lesser part is composed of reflections from the ground and other objects. Diffuse radiation does not have directional beaming; although its intensity is different for various orientations, it strikes at all angles.

CHOOSING CLEAR SKY CONDITIONS FOR DESIGN PURPOSES

The relative importance of diffuse and direct radiation varies with cloudiness.[38]

During cloudy days the ratio may be 1.00 (100 percent diffuse radiation) while during clear days it may be only 0.15 (15 percent diffuse radiation). However, the overall heat received on a cloudy day (diffuse radiation, primarily) is much less than the overall radiation received on a clear day (direct plus diffuse radiation). For example, the following are the relative proportions of radiation received on a vertical wall facing south under average cloudiness for New York in January:

Clear days account for
75 percent of the total solar heat received,
of which 19 percent is due to diffuse radiation.

Partly cloudy days account for
18 per cent of the total solar heat received,
of which 56 percent is due to diffuse radiation.

Cloudy days account for
7 per cent of the total solar heat received,
of which 100 percent, or all of it, is due to diffuse radiation.

This classification exemplifies the point that the largest portion of the total solar radiation arrives during times when the ratio of diffuse to total radiation is smallest, that is, during clear days.

A somewhat similar situation is noted when the daily variation of the ratio of diffuse to total radiation is examined during a clear August day on a vertical surface facing south. The average value of the ratio of diffuse to total radiation for the day is equal to 0.26 (26 percent diffuse radiation):

60 percent of the total solar heat arrives during 4.3 hours of the day (32 percent of the daylight hours) when diffuse to total radiation equals 0.2 (20 percent diffuse radiation).

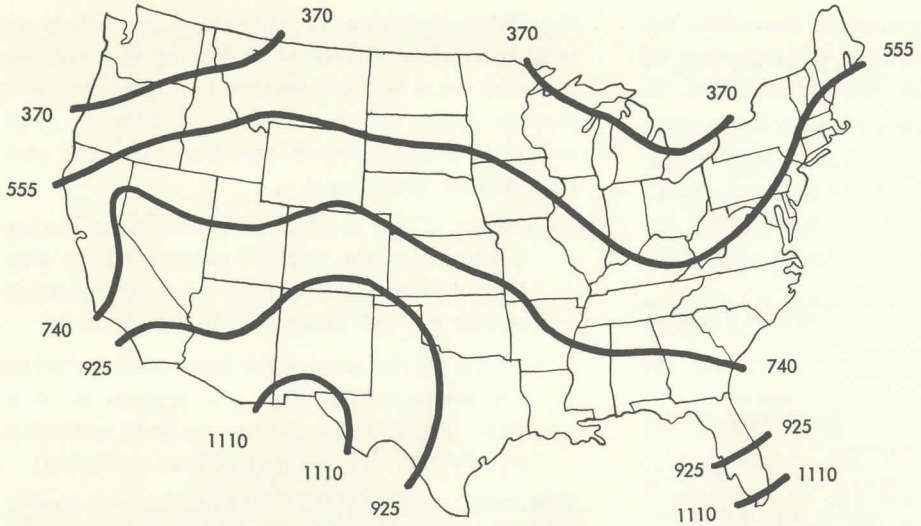
32 percent of the total solar heat arrives during 5.4 hours of the day (41 percent of daylight hours) when diffuse to total radiation equals 0.32 (32 percent diffuse radiation).

3 percent of the total solar heat arrives during 3.6 hours of the day (27 percent of the daylight hours) when diffuse to total radiation equals 1.00 (100 percent diffuse radiation).

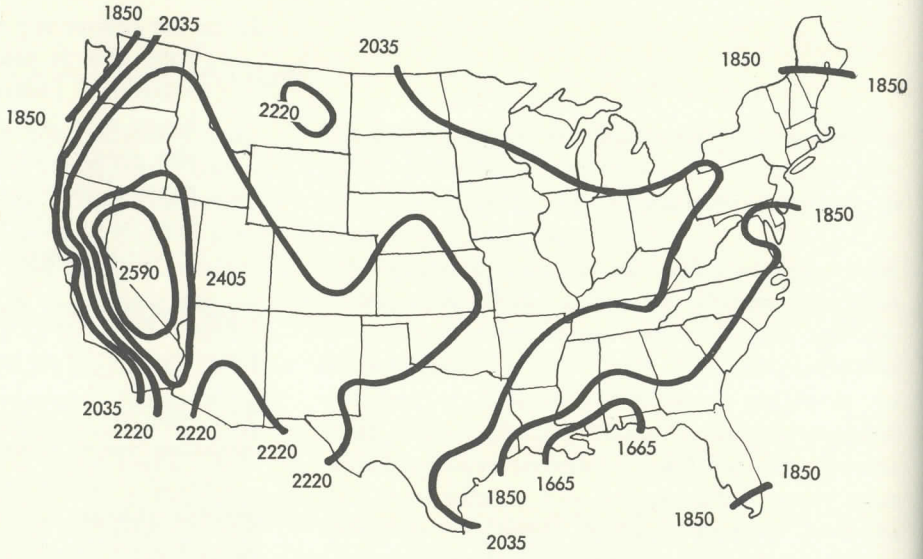
This shows that during clear days direct radiation contributes much more to the total solar heat gain than does diffuse radiation.

In addition to clear-sky values, a knowledge of average radiation is required in the problems of solar openings, solar collectors and specialized heat-flow calculations. For any given latitude and season clear-sky radiation is modified by the effects of cloudiness and turbidity in the atmosphere, so that the total radiation is reduced and the ratio of diffuse to total is increased. Since such information is not directly obtainable from Weather Bureau data, an empirical relationship between a parameter which is measured at Weather Bureau stations and the average radiation on the various surfaces is necessary. It has been found that the monthly percentage of clear, partly cloudy and cloudy days may be used as such a parameter.

In the problem of solar control the architect's interest lies more toward the design conditions. Clear days in the summer mean warmer days because of the increased solar energy. Con-



112. Average daily sun energy received in January.



113. Average daily sun energy received in July.

versely, a clear day in winter marks a day with lower average temperatures because in the longer period of outgoing radiation from buildings to sky, heat escapes more easily through a cloudless atmosphere. Therefore "clear sky" radiation in both summer and winter is a good basis for design purposes, because it includes the extremes of radiation gain and loss.

The modifying effects of atmospheric conditions can be quite clearly seen in the two maps (Figs. 112, 113) which show the average daily sun-heat (in Btu/sq. ft.) received on a flat surface in January and in July.[39]

It will be noticed that in January the lines designating solar-heat values run generally east-west. Were there no modifying atmospheric conditions the lines would run strictly parallel, as the amount of heat received is a function of the length of the day and of the cosine of the angle of incidence. This angle varies with latitude and plays an important part when the sun is low in the sky. Any deviation from parallel east-west lines is therefore a result of cloudiness, turbidity, topography and other local atmospheric conditions.

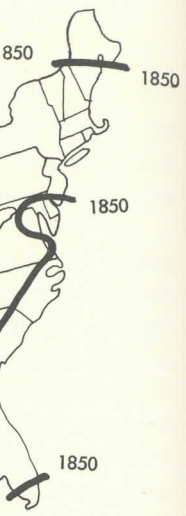
These effects are even more evident on the July chart. Because of the almost vertical sun's rays, changes in latitude are less important and the solar heat received should be almost equal from north to south throughout the country. The large variations shown on the map are, then, almost entirely the result of local atmospheric conditions.

CALCULATION METHODS

The various approaches to calculation of solar radiation can be categorized under two headings. One is the tabulative, or statistical method; the other the diagrammatic, or graphic method.

The aim of this chapter is not to describe in detail all the existing methods, but rather to refer to those which are of practical purpose for the design architect or engineer. Practical usability means certain standardized values, and these, as such, are limited to certain conditions. The intensities of radiation values in the calculation methods described here are all based on the standards used by the American Society of Heating and Ventilating Engineers, and published in their Guide.[40] In the ASHVE standards the direct normal radiation is based on Moon's proposed standards[41] calculated for sea level, 20 mm. precipitable water vapor, 300 dust particles per cu. cm, 2.8 mm. Hg partial pressure of ozone. These values are representative of a clear summer day. The radiation values for "industrial atmospheres" were derived from sol-air data for New York City.[42] The data on diffuse or sky radiation are based on observations made by the ASHVE research station in Cleveland. The diffuse values include a certain amount of ground radiation.

As indicated previously, changes in the amount of water vapor and dust in the atmosphere and local climatic conditions may alter the intensities for a specific location, as may the seasonal sun energy, or the altitude of the building under study. Therefore some judgment is required in applying the design radiation data to a given geographical location.



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CALCULATION WITH TABULATED DATA

As described before, in order to calculate solar energy we need first to know the amount received at normal incidence in relation to the solar altitude. Secondly, we need to know the incident angle to the specific surface in question in order to reduce the energy to its cosine function.

The intensity is conveniently tabulated for engineering use.[43] In table A intensities are given for both direct and diffuse radiation in two kinds of atmospheres. Table B gives values for the incident angle with its corresponding cosine functions for 40° N. latitude in summer period.

The data shown in the tables can be applied only for the given orientations, times and latitudes. For other latitudes and seasons data can be obtained from various sources, such as the Ephemeris of the Sun,[44] or the Hydrographic Office Bulletin.[45] To compute K values for orientations other than tabulated above, the values of solar azimuth and altitude are required. Table C indicates the data for the summer period for latitude 40° N. The solar altitude degree is needed also in the calculation of diffuse energy.

Table A. Values of Idn, Direct Solar Radiation Received at Normal Incidence at the Earth's Surface and Values of I_d, Diffuse or Sky Solar Radiation, Received by Variously Oriented Surfaces

Btu per (hour) (square foot)

Solar Altitude β Degrees	For Clear Atmospheres: Direct Normal Radiation	Diffuse or Sky Radiation					For Industrial Atmospheres: Direct Normal Radiation	Diffuse or Sky Radiation				
AM →		N	E	S	W	Horiz.		N	E	S	W	Horiz.
5	67	6	11	4	4	7	34	4	11	5	3	9
10	123	11	20	8	7	14	58	8	22	9	7	18
15	166	14	27	11	10	19	80	11	28	13	9	24
20	197	15	32	13	12	23	103	13	36	17	12	31
25	218	16	35	15	13	26	121	16	43	21	16	38
30	235	17	36	17	15	28	136	18	47	24	18	44
35	248	17	36	19	16	30	148	19	50	27	21	48
40	258	18	36	21	17	31	158	20	50	30	23	52
45	266	19	35	23	18	32	165	21	49	31	25	55
50	273	19	33	25	19	33	172	22	47	34	27	58
60	283	21	28	27	21	34	181	22	41	37	30	63
70	289	22	23	29	23	35	188	22	34	41	34	69
80	292	—	—	—	—	—	195	—	—	—	—	—
90	294	—	—	—	—	—	200	—	—	—	—	—
PM →		N	W	S	E	Horiz.		N	W	S	E	Horiz.

Table B. Values of K, the Cosine of the Incident Angle for Variously Oriented Walls and a Horizontal Surface Computed for 18 Deg Declination, North (August 1)

40 Deg North Latitude

Sun Time		Cosine K of the Incident Angle						
AM →		N	NE	E	SE	S	SW	Horiz.
5 a.m.	7 p.m.	0.406	0.934	0.914	0.358			0.009
6	6	0.237	0.840	0.951	0.505			0.199
7	5	0.079	0.705	0.919	0.594			0.391
8	4		0.533	0.824	0.631	0.069		0.566
9	3		0.337	0.673	0.614	0.196		0.713
10	2		0.129	0.475	0.542	0.292		0.829
11	1			0.246	0.424	0.354	0.076	0.903
12				0.000	0.265	0.375	0.265	0.927
PM →		N	NW	W	SW	S	SE	Horiz.

Table C. Values of the Wall Solar Azimuth, γ, for Variously Oriented Walls and Solar Altitude Computed for 18 Deg Declination, North (August 1)

40 Deg North Latitude

Sun Time		Solar Altitude β Degrees	Azimuth Angle γ, Degrees					
AM →			N	NE	E	SE	S	SW
5 a.m.	7 p.m.	0.5	66	21	24	69		
6	6	11.5	76	31	14	59		
7	5	23.0	85	40	5	50	shade	
8	4	34.5	shade	50	5	40	85	
9	3	45.5		61	16	29	74	
10	2	56.0		76	31	14	59	shade
11	1	64.5		shade	55	10	35	80
12		68.0			90	45	0	45
PM →			N	NW	W	SW	S	SE

CALCULATION OF SOLAR ENERGY WITH RADIATION CALCULATOR

The previous description dealt with the calculation of radiation through the use of tabulated data. This method however is time-consuming and laborious.

Some graphical systems have advantages over the statistical approach. A method was developed by Friedrich Tonne[46] whereby equi-intensity lines were charted on a horizontally projected half-sphere. According to the sun's position, the received intensity index number has to be multiplied by separately charted radiation values. Another approach was accomplished with the "Sun Angle Calculator."[27] Here, although the altitude and incidence angles have to be read from the sun-path diagram beforehand, the radiation energies can be determined with the use of alignment charts.

The authors, aided by both of the previously mentioned methods, developed a Radiation Calculator where for any orientation not only the direct, but the diffuse and the total radiation effects can be determined with one reading.[47]

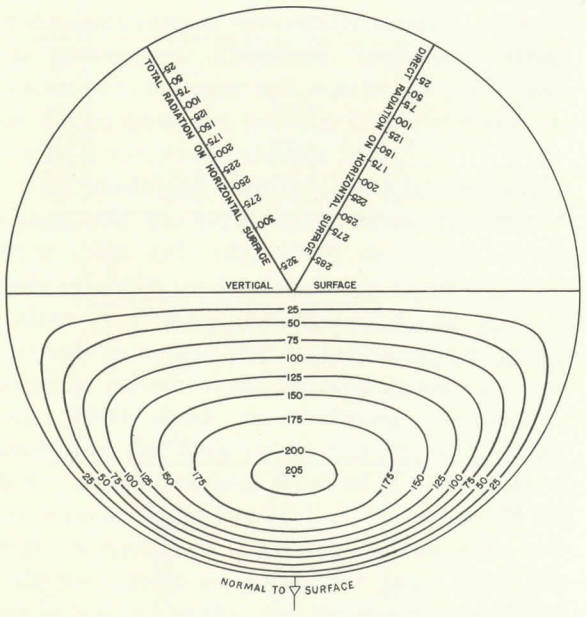
The Calculator charts are based on the assumption that the magnitude of the direct and diffuse radiation is a function of the solar altitude and the angle of incidence of the sun. On a sphere the equal altitude variations to a central point would show parallel circles; the variation of equal incidence angles would appear in form of concentric cones. Therefore it is evident that to any given altitude and incidence situation two points will correspond symmetrical that is, they will be symmetrical to a vertical plane normal to the wall surface.

Hence all possible radiation effects can be charted in relation to a given surface on a spherical projection.

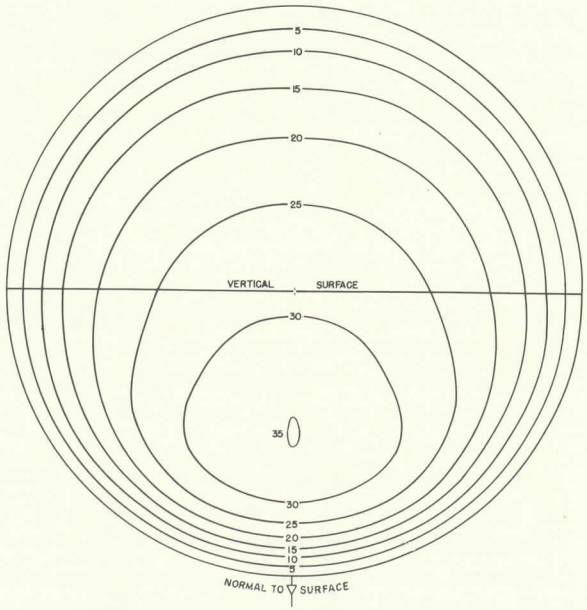
The Calculator diagrams are projected horizontally in the equidistant method. The charted energy values are representative for clear day and unobstructed sky conditions. The direct radiation data corresponds to Moon's standard,[37] the diffuse values to ASHVE recommendations.[48]

Since in architectural problems the irradiation of vertical and horizontal surfaces are of primary interest, the charts were developed for these exposures; however, the method can be adapted to any oblique plane. The Calculator diagrams can be used for any latitude and for all orientations. As the total radiation falling on a surface can be read directly for any hour of the year, the flexibility and rapidity of this Radiation Calculator has its obvious advantages for use in architectural tasks.

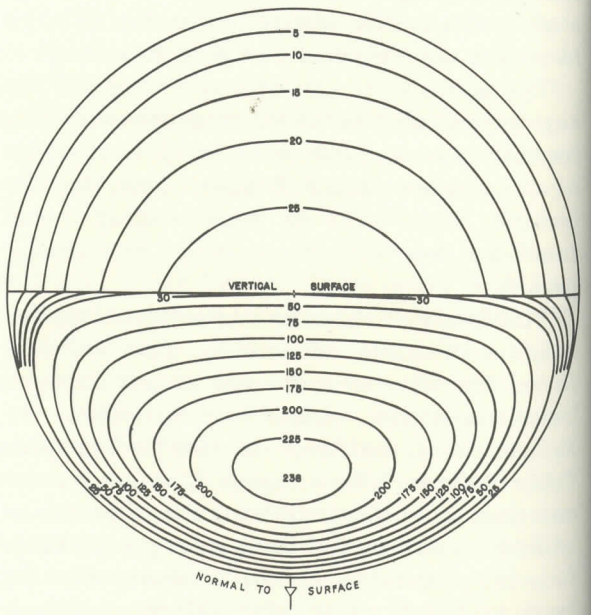
Fig. 114 shows at the lower half circle the



114. Direct Radiation Calculator.



115. Diffuse Radiation Calculator.



116. Total Radiation Calculator.

amounts of direct radiation falling on a vertical plane; on the opposite side the measures indicate the sun's energies on a horizontal surface. The equi-intensity radiation lines are indicated at 25 Btu/hour/sq. ft. intervals. Fig. 115 charts the diffuse energies on a vertical surface at 5 Btu/hour/sq. ft. intervals. Note that the vertical surface receives sky radiation even when the sun's angle of incidence exceeds 90.° Fig. 116 shows the total radiation amounts received by a vertical surface. The chart tabulates the added energy amounts of both the direct and diffuse radiation.

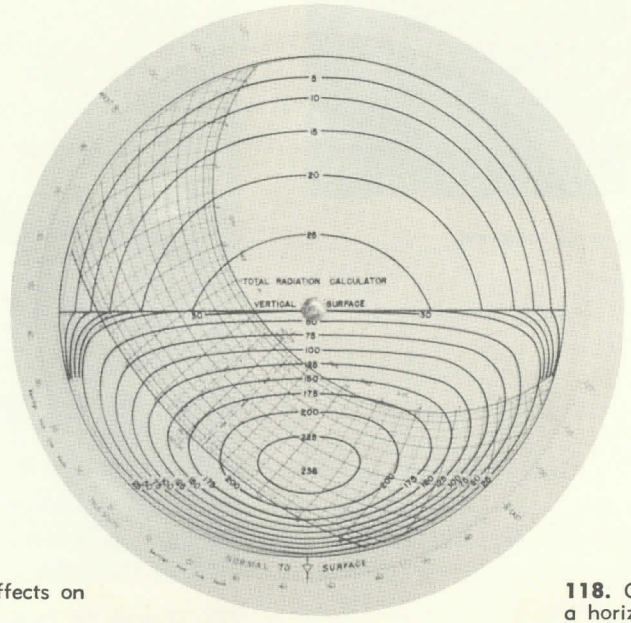
USE OF THE RADIATION CALCULATOR

For practical application the intensity diagrams are charted on transparent overlays. These may be superimposed on a sun-path diagram to read directly the amount of energy being received.

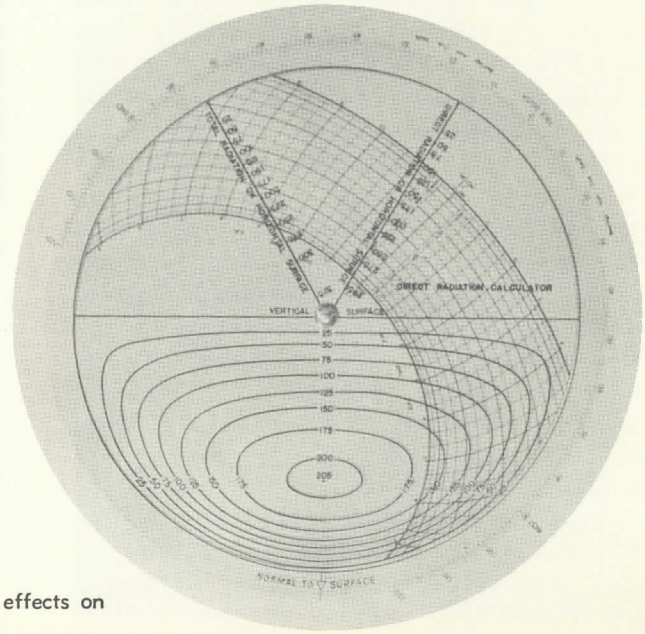
In use the following steps should be taken:

1. Select the sun-path diagram which in latitude is nearest to the given location.
2. Superimpose the desired intensity overlay on the sun-path diagram.
3. Turn the overlay to the orientation in question. (The bearing angles marked at the outer perimeter of the sun-path diagram and the "normal to surface" arrow on the overlay should be used for this purpose.)
4. Locate any desired day and hour throughout the year on the sun-path diagram and read from the overlay the radiation intensities reaching the surface. (If the point lies between the marked intensity curves one should interpolate its value from the nearest data.)

Two examples show the application of the Radiation Calculator. The first diagram (Fig. 117) illustrates the calculation of radiation



117. Calculation of radiation effects on a vertical surface.



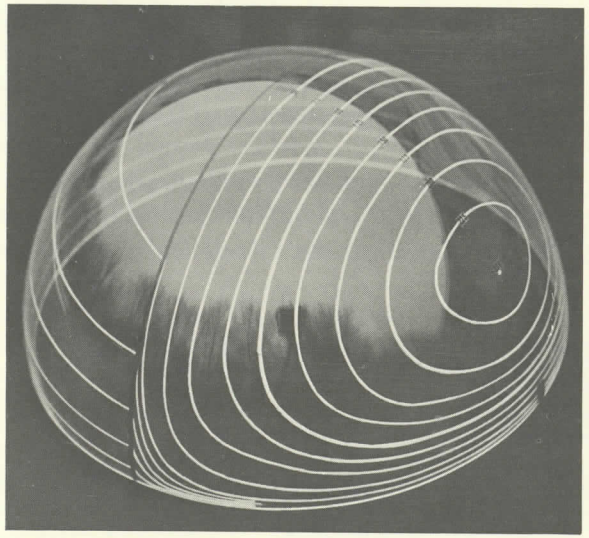
118. Calculation of radiation effects on a horizontal surface.

effects on a vertical surface. Assume that the building under study is located in Princeton, N. J. (40° 21′ N.), and that the aim is to determine these total radiation effects on a wall facing southeast at June 21. The nearest sun-path diagram is 40° N.; the total radiation overlay is superimposed on it and turned 45° east from south. June 21 is at the upper perimeter on the sun-path diagram over which the hourly radiation readings are as follows:

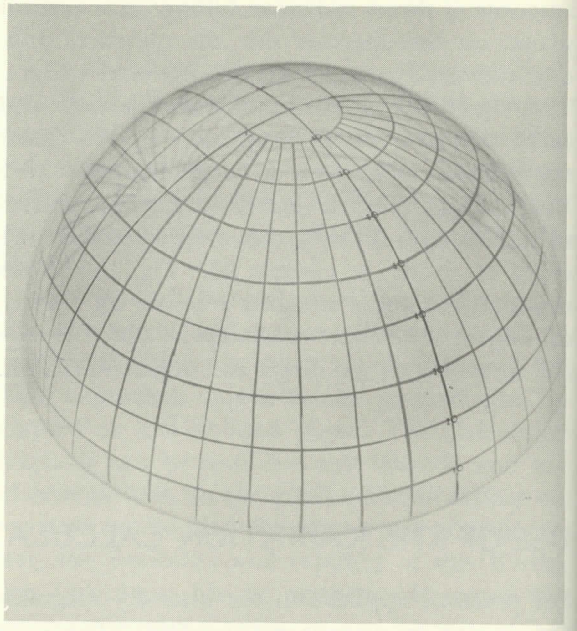
The sun rises at 4:35 A.M.; at 5:00 radiation is 25 Btu; at 6:00, 87 Btu (interpolated value); at 7:00, 138 Btu; at 8:00, 170; at 9:00, 178; at 10:00, 164; at 11:00, 130; at noon, 87; at 1 P.M., 30 (from this reading on, as the sun leaves the surface, only diffuse radiation reaches the wall); at 2:00, 27; at 3:00, 23; at 4:00, 21; at 5:00, 17; at 6:00, 11; at 7:00, 4 Btu; and the sun sets at 7:25. The total daily radiation which reaches the surface adds up to 1112 Btu/sq. ft./day.

The second example (Fig. 118) illustrates the calculation of radiation on a horizontal surface. Let us assume the same location and time as in the example before but with the aim of determining the total radiation on a flat roof at 9:20 A.M. As the horizontal effect can be considered as non-directional the overlay with the marking "total radiation on horizontal surface" can be rotated to any orientation on the sun-path diagram. Turning the overlay to the time in question, the reading is 250/Btu/hour/sq. ft.

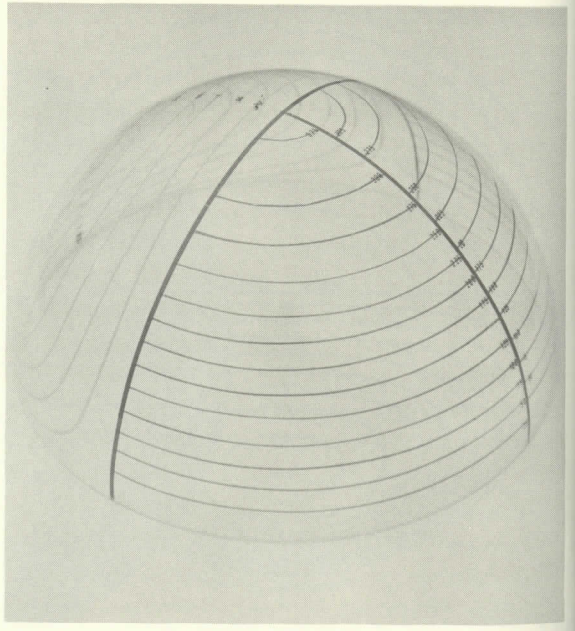
The Radiation Calculator, as was mentioned before, is calibrated to clear sky conditions, because cloud-free days fulfill design requirements. In a similar manner calculators can be developed for semi-cloudy and cloudy conditions. Thus, given the relative percentages of clear, partly cloudy, and cloudy hours, a month's average radiation conditions could be computed.



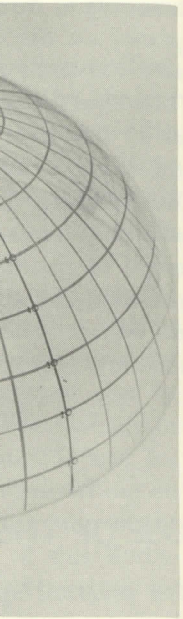
120. Overlay to determine total radiation.



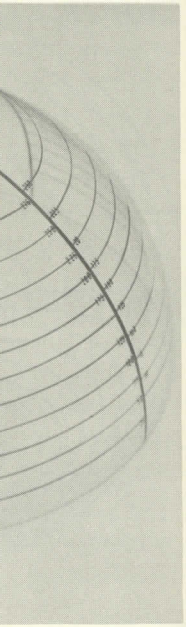
119. Overlay to determine altitude and bearing angles.



121. Overlay for total radiation on horizontal surfaces.



nd bearing angles.



horizontal surfaces.

SPHERICAL RADIATION CALCULATOR

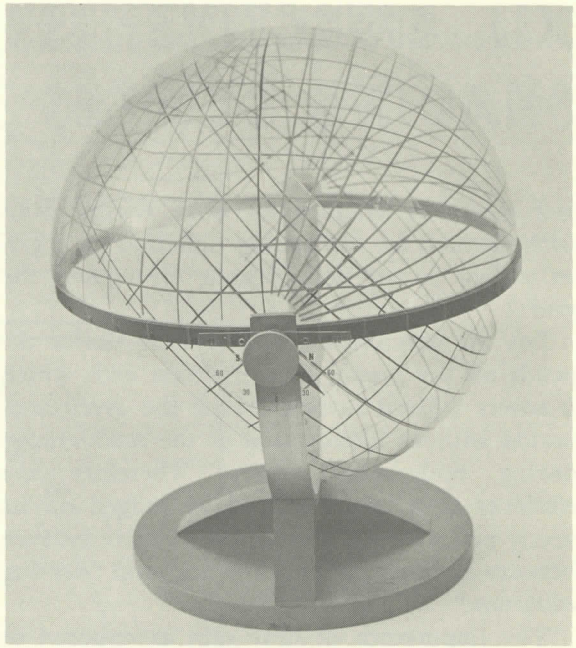
As a further step in the radiation calculation methods a spatial device was constructed in the Architectural Laboratory of Princeton University. The calculator consists of a horizontally pivoted sun-path which can be rotated to any latitude, in either the Northern or Southern Hemisphere.

On transparent half-globes, marked with radiation intensities and placed over the path in the desired orientation degree, the energy impacts at any hour of the year can be read directly. The spatial radiation calculator has the advantage that it can be set to any required latitude, and it proves to be a practical tool for visual comprehension of the sun's movements and energies.

The magnitude of the radiation impacts charted on the hemispherical overlays were computed in the same way as those described on the previous pages. Fig. 119 shows an overlay used to determine altitude and bearing degrees. Fig. 120 demonstrates another plastic hemisphere with total radiation values charted for a vertical surface (the darker line at about the middle of the picture). Fig. 121 shows total radiation impacts falling on a horizontal plane (nearest section).

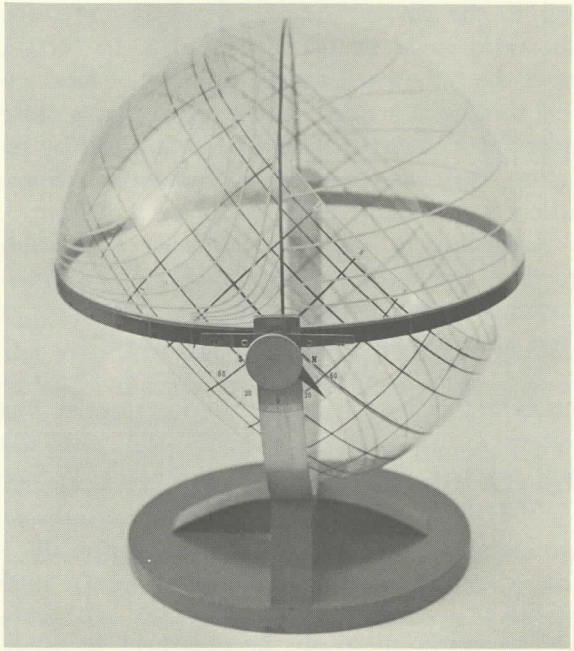
To use this spatial radiation calculator the following steps should be taken:

1. Set the sun-path at the appropriate altitude angle for the location (see protractor on the stand's pivot).
2. Superimpose the required radiation overlay sphere on the horizon circle in the desired orientation (see 10° markings on the horizontal ring).
3. Read the radiation intensities at any day and hour throughout the year directly from the overlay.



122. Spherical radiation calculator in a position where the sun's angles can be measured at 40° N. latitude.

123. The calculator at the same latitude set for reading total radiation impacts on a south-facing surface.



XII. EFFECTIVENESS OF SHADING DEVICES

THE preceding chapter on solar energy dealt with methods for calculating radiation on a given surface at any desired hour throughout the year.

But the effectiveness of a shading device depends on the proportionate success with which it covers a given surface during the overheated period without interception of the sun's energy during underheated times. Therefore the efficiency of a device should be judged on its yearly performance, and on the relative balance between its "shading performance" and "heating efficiency."

The importance of heat gain as opposed to "cooling" shade can be interpreted by different ratios. In fully air-conditioned buildings, according to the current heating-versus-cooling costs, the ratio could be taken as 1 to 5. In certain cases the ratio based on the economy of mechanical cooling is justfied. But it seems that a more permanent yardstick would be established by relating their importance to human reactions, where a reasonable ratio would be 1 to 2.

According to this, the following evaluation methods are based on the assumption that shading at overheated times is twice as important as heat gain during the underheated period.

The summer shading performance (S_p) can be expressed by comparing the intercepted Btu values during overheated times (S_o) with the full amount of Btu's which strike the surface during the overheated period (R_o):

$$S_p = \frac{S_o}{R_o} \cdot 100\%$$

The yearly effect can be expressed in terms of heat efficiency (H_e) by deducting the Btu losses during the shaded underheated period (S_u) from S_o values and writing the result in percentages:

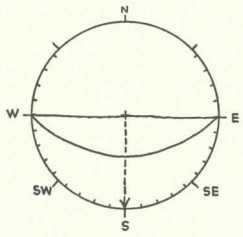
$$H_e = \frac{S_o - S_u}{R_o} \cdot 100\%$$

In the final evaluation both methods are of interest: the heat efficiency as a yearly balance for the use of the shading device, and the shading performance as an optimum for the summer season. Therefore, the average value of the two equations gives a formula called the shading effect ratio (S_e):

$$S_e = \frac{S_p + H_e}{2} = \frac{\frac{S_o}{R_o} + \frac{S_o - S_u}{R_o}}{2} = \frac{S_o - \frac{S_u}{2}}{R_o} \cdot 100\%$$

By using the above formulae, shading devices can be evaluated for any locality or desired direction. For practical purposes, since the aim is to find the shading properties of overhangs, certain simplifications can be allowed in the cal-

SHADING DEVICE EVALUATION



TYPE OF MASK

TYPE OF DEVICE : SOLID FIXED OVERHANG
PROFILE ANGLE : 65°
LATITUDE : 40°N
ZONE : N.Y. - N.J. AREA
NOTE :

N.B. DIRECT RADIATION B.T.U. VALUES ARE TABULATED IN 3 HOURS 20 MINUTE UNITS AT CLEAR DAYS ON ONE SQUARE FOOT. THIS IS TRANSFORMED INTO AVERAGE SUMMER SUNSHINE HOURS (66%) AND TO HOURLY BASE WITH "C" FACTOR (C = 2·2, IN N.Y.-NEW JERSEY AREA)

B.T.U./SQ.FT. TILL	SHADED OVERHEATED (S_o) 50 - 100%		SHADED OVERHEATED (S_o) 100%		SHADED UNDERHEATED (S_u) 50 - 100%		SHADED UNDERHEATED (S_u) 100%		DIRECT RADIATION AT OVERHEATED TIMES (R_o)
25		75	1	000		200		875	1 050
50		150	2	000		400	1	150	2 150
75		375	4	280	1	125	1	800	4 700
100		800	6	400	1	800	2	600	7 400
125	2	000	2	125	3	120	2	125	4 125
150	3	600			5	250			3 450
175	1	575			5	410			1 400
200					1	600			
0.75 x	8	575			18	905			
C x	6	440	15	805	14	200	8	550	24 275
	14	510	34	800	31	200	18	800	
TOTAL B.T.U. S_o =			48	950	S_u =		50	000	R_o = 53 300

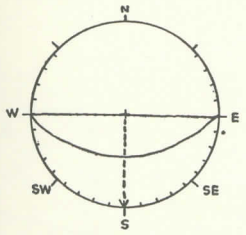
SUMMER SHADING PERFORMANCE $(S_P) = \frac{S_o}{R_o} 100\% = \frac{48,950}{53,300} 100\% =$ **92 %**

YEARLY HEAT EFFICIENCY $(H_E) = \frac{S_o - S_u}{R_o} 100\% = \frac{48,950 - 50,000}{53,300} 100\% =$ **-2 %**

SHADING EFFECT RATIO $(S_E) = \frac{S_P + H_E}{2} = \frac{92 - 2}{2} =$ **45 %**

124. Shading device evaluation.

SHADING DEVICE EVALUATION



TYPE OF MASK

TYPE OF DEVICE : SOLID FIXED OVERHANG
PROFILE ANGLE : 70°
LATITUDE : 40°N
ZONE : N.Y. - N.J. AREA
NOTE :

N.B. DIRECT RADIATION B.T.U. VALUES ARE TABULATED IN 3 HOURS 20 MINUTE UNITS AT CLEAR DAYS ON ONE SQUARE FOOT. THIS IS TRANSFORMED INTO AVERAGE SUMMER SUNSHINE HOURS (66%) AND TO HOURLY BASE WITH "C" FACTOR (C = 2·2 , IN N.Y.-NEW JERSEY AREA)

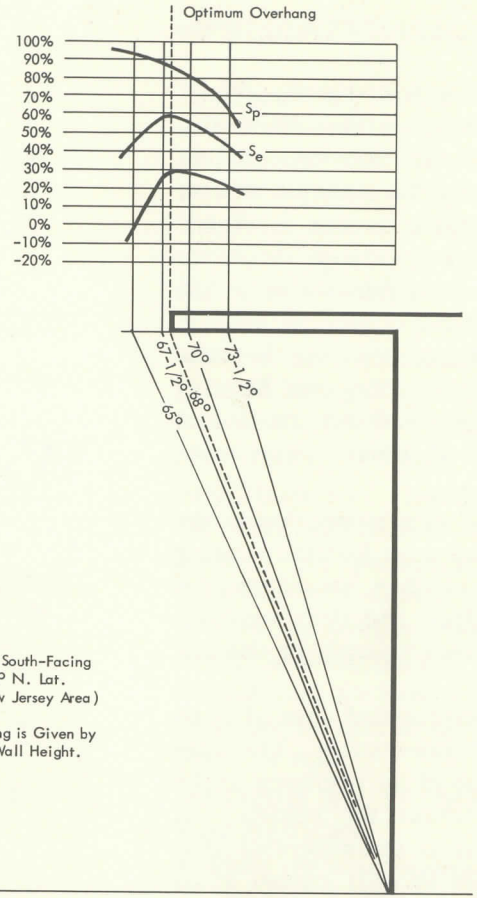
B.T.U./SQ.FT. TILL	SHADED OVERHEATED (S_o) 50 - 100%		100%		SHADED UNDERHEATED (S_u) 50 - 100%		100%		DIRECT RADIATION AT OVERHEATED TIMES (R_o)	
25		75	1	000		200		875	1	050
50		200	2	050		500		950	2	150
75		675	3	880	1	270	1	200	4	700
100	1	800	5	100	2	400	1	200	7	400
125	3	870			4	350			4	125
150	3	000			3	000			3	450
175		525				525			1	400
200										
0.73 ×	10	145			12	245				
C ×	7	600	12	030	8	570	4	225	24	275
	16	800	26	400	18	820	9	300		
TOTAL B.T.U. S_o =			43	200	S_u =		28	120	R_o = 53	300

SUMMER SHADING PERFORMANCE $(S_p) = \frac{S_o}{R_o}\ 100\% = \frac{43,200}{53,300}\ 100\% =$ **81 %**

YEARLY HEAT EFFICIENCY $(H_E) = \frac{S_o - S_u}{R_o}\ 100\% = \frac{43,200 - 28,120}{53,300}\ 100\% =$ **28 %**

SHADING EFFECT RATIO $(S_e) = \frac{S_p + H_E}{2} = \frac{81 + 28}{2} =$ **54,5%**

125. Shading device evaluation.



Evaluation of a South-Facing Overhang at 40° N. Lat. (New York-New Jersey Area)

Optimum Shading is Given by 68° or 41% of Wall Height.

126.

culations. The effects of different materials, their color, reflection, and heat transfer are factors which can be disregarded in the evaluations. Direct clear radiation can be used as a measure, and the shading effects can be simplified into two categories; the 50-100% shading effect (calculated with 75% average value) and the 100% shading (calculated at full value).

As an example of this method a south-facing overhang is evaluated from the New York-New Jersey area. The numerical calculations (Figs. 124, 125) tabulate the yearly radiation intensities in 25 Btu intervals in categories of shaded overheated, shaded underheated, and the amount of radiation which was received during overheated times. This is done by overlaying the "shading mask" protractor on the "direct radiation" protractor. Readings are categorized according to the "sun-path diagram." At the sum totals, "c" stands for a conversion factor on an hourly basis and into the average summer sunshine hours for the region.

By calculating various-sized overhangs in the same manner the results can be plotted together (Fig. 126). Here the overhang with an altitude angle of 65° has a shading effect ratio of 45%, the 67½° has 56.6%, at 70° S_e has 54.5%, and at 73½° S_e drops to 40%. As the optimum effect is at the overhang with a 68° altitude angle ($S_e = 58\%$), this size would be recommended in the New York-New Jersey area with a south orientation.

Turning from the south toward the east, the heat efficiency of an overhang soon drops below zero. The depth limit of an overhang is 78° in southeast orientation. Facing southwest, the

depth limit of an overhang is 76°, with a low shading effect ratio.

Facing east or west, we find that fixed horizontal overhangs have negative heat efficiencies. Therefore, their use toward these orientations is not recommended from the point of view of heat balance. Here movable devices or vegetation will help. Minimum overhangs should be used only to avoid frost and rain effects on the wall surfaces.

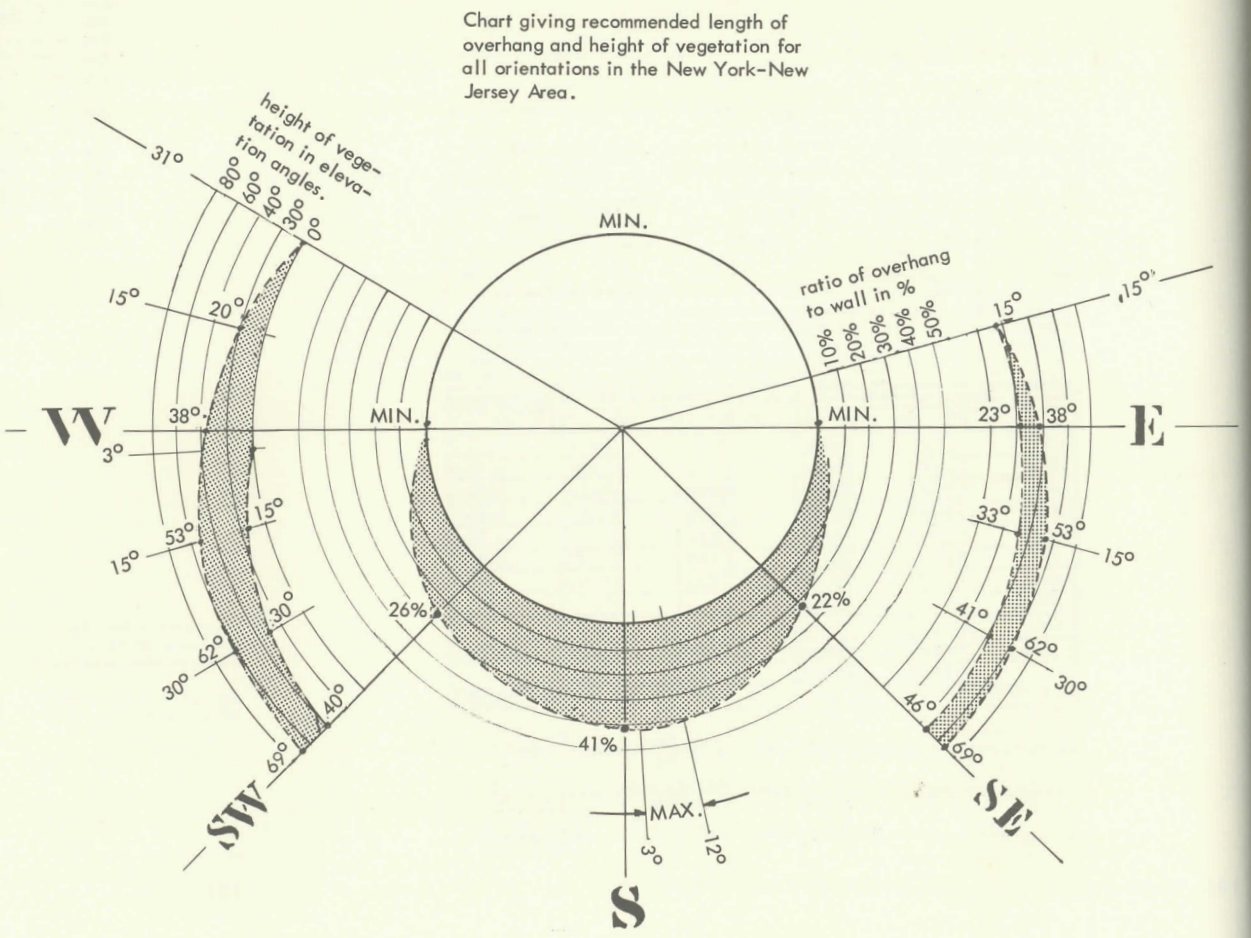
The results of the calculations can be summarized in a diagram called "Regional Shading Chart." This chart, prepared for residential structures in the New York-New Jersey area, is shown in Fig. 127.

At this point it is well to mention that in the case of tall buildings one must find the shading solution by other means than overhangs and shade trees. Such problems and their solutions are described and illustrated amply in the last part of the book.

The chart shows recommended sizes of fixed overhangs for different orientations. The sizes are indicated by the ratio of the overhang to the wall, in percentages. Where the efficiency of the overhang is low, it is recommended that vegetation or shade trees be used instead of an overhang wherever possible.

Deciduous trees have a high shading effect ratio (between 50-60%) because the duration of their foliage coincides roughly with the duration of the overheated period. The desirable positions of the trees are charted with their elevation and bearing angles.

All the shading needs are indicated on the chart. Although at low sun altitudes, when the intensity of radiation is accordingly low, there is a practical limit to the necessity for shading. The recommended length of an overhang is given on the chart on a line perpendicular to the wall in question. The elevation angles of the trees are similarly found.



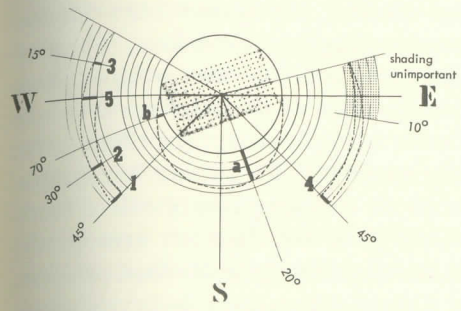
127. Regional Shading Chart, giving recommended length of overhang and height of vegetation for all orientations in the New-York-New Jersey area.

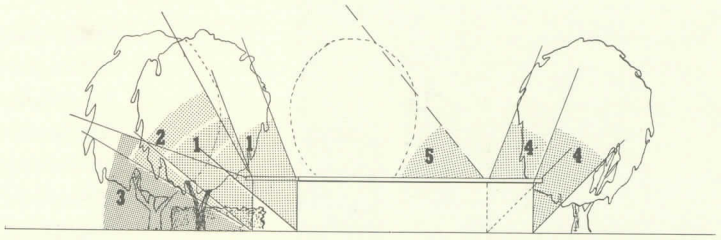
An example of the application of the Regional Shading Chart is shown in Fig. 128.

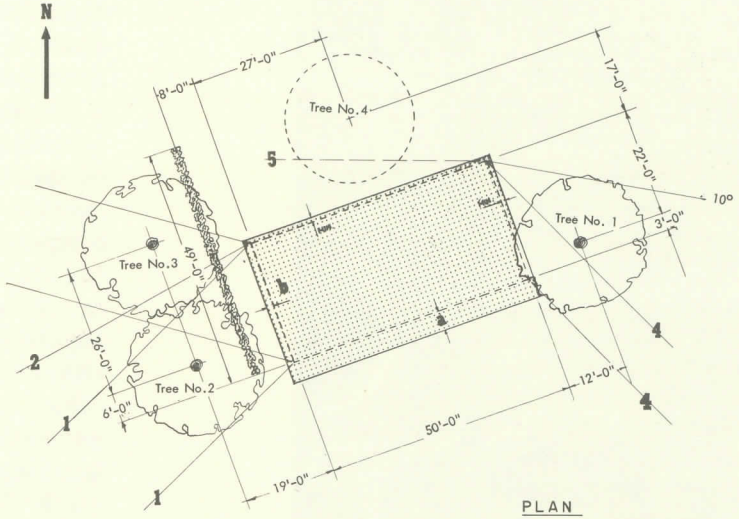
Efficiencies of vertical shading devices were calculated, but were found to work negatively in this area. Eggcrate devices are similarly inefficient. Therefore, they should be used with caution. Their use in this area is justified only in a case where the summer shading performance rather than the yearly heat balance is of importance, such as office buildings with large glass surfaces. In these cases the shading performance would be the only decisive factor.

The regional shading chart gives dimensions for fixed devices only. Movable devices have a higher performance, because they can be adapted to the different shading needs in the spring and autumn. Their most effective application would be on east-to-southeast and southwest-to-west

EXAMPLE OF THE APPLICATION OF THE REGIONAL SHADING CHART FOR THE NEW YORK - NEW JERSEY AREA.







PROCEDURE:

1. Place the outline of the building in proper orientation in the center of the Regional Shading Chart. On the lines perpendicular to the walls of the building read off the recommended sizes of overhangs (a, b).
2. Plot the bearing angles, finding corresponding elevation angles (1-5) of the shading trees.
3. Plot the bearing angles on the plan.
4. Plot the elevation angles on the elevation of building.
5. Decide on the types and sizes of trees and shrubbery. Place them both on the plan and elevation in such a way that they fill in both the bearing and elevation angles.

NOTE:

Tree No. 4 is needed only in case of a large glass area on the North wall.

128. Application of Regional Shading Chart in an example.

orientations, where the altitude and the bearing of the sun show large variation of conditions.

In other climatic zones the regional shading charts would differ considerably. In cold regions where the overheated period is shifted away from the summer solstice axis, fixed overhangs will cut out too much beneficial sun heat. There, movable devices or vegetation is the right answer. In moderate climates the chart would be more or less similar to that of the New York region. In warm climates where the overheated period exceeds the underheated period, larger horizontal overhangs are needed, and the use of vertical and eggcrate devices will be justified. On the south side the horizontal overhang, on the southwest the eggcrate, and on the westerly side vertical devices will be efficient.

Calculated regional shading charts for the different climate zones would be effective and practical tools in the hands of architects.

APPLICATIONS

For the practical use of shading calculations, one can choose between different methods. The choice of method will depend on the task and on the required precision. For quick estimates, the No. 1 method seems adequate because shading needs can be read directly from the chart. For architects who want to design their own shading devices, construction method No. 2 is advisable. In the case of buildings where large exposed glass areas would require a more precise determination of heat gains and losses, the calculation method No. 3 is recommended.

METHOD NO. 1: DIRECT APPLICATION OF THE REGIONAL SHADING CHART.

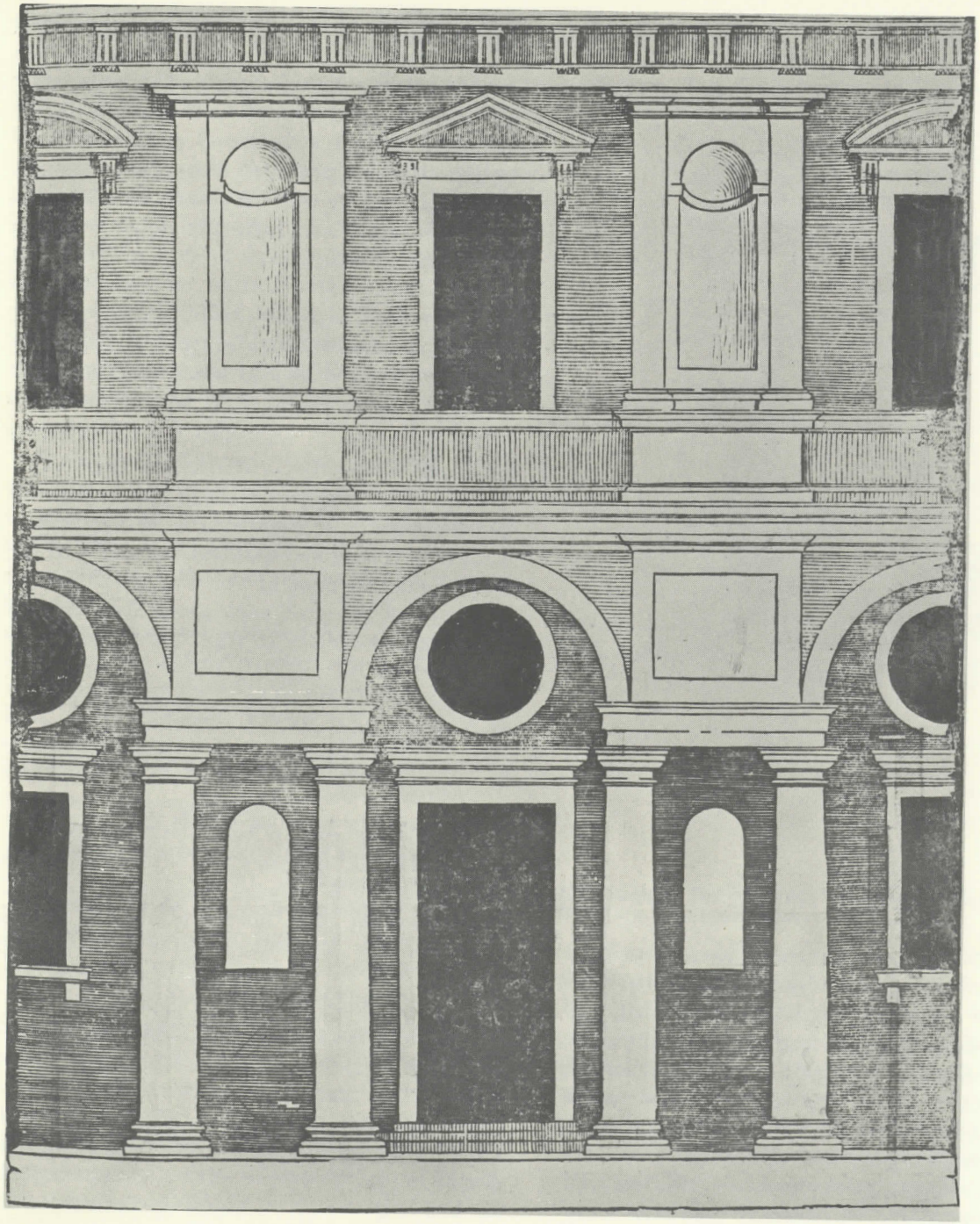
On a line perpendicular to the surface in question, read directly the size of the recommended overhang and the elevation angles of the needed shading trees. If the whole wall should be protected, the lower angle should be measured from the bottom of the wall, the higher angle from the top.

METHOD NO. 2: THE DESIGN OF SHADING DEVICES.

A. Place the mask protractor over the overheated-period chart.
B. Determine a mask of which the 50 percent border most nearly coincides with the overheated period.
C. Design a device which has these mask characteristics. (In case of a one-story house, trees can be located with their elevation and bearing angles on the mask.)

METHOD NO. 3: HEAT CALCULATION METHOD.

The procedure is the same as in method No. 2, but with the necessary Btu calculations as described on page 64. Evaluation of the efficiency should be in accordance with the character of the building.



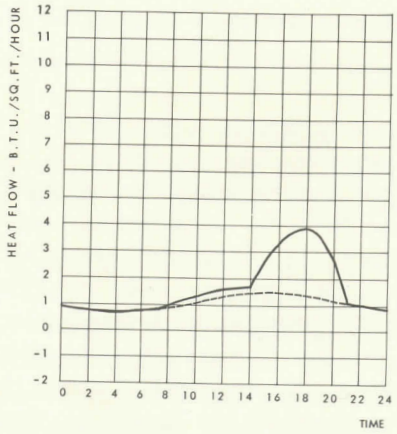
129. Facade after Serlio, mid-sixteenth century.

XIII. HEAT TRANSMISSION OF MATE

THE transition from masonry wall to skeleton construction created new possibilities for expression in the design of elevations. Theoretically nothing now prevents the architect from handling the facades of a building as whole "window walls." The usual New York office building averages 22% glass surface in its elevations; however, a building like the UN Secretariat opens 68% of its elevation area to the light. With this freedom the solar load problem, which was a negligible aspect before, emerges greatly enlarged.

To contrast a solid wall to a glass window as a radiation transmitter seems a rather one-sided competition, since one is opaque and the other transparent to the rays. It is more realistic to compare their role as heat barriers with their full thermal performance. Periodic heat-flow calculations were used for this purpose to integrate convection, conduction and radiation effects.

For this comparison an average clear summer day (July 21) was chosen in Miami, Florida. Both surfaces have a west exposure. The first graph (Fig. 130) shows the heat transmission of



130. Heattransmission of a wooden wall.

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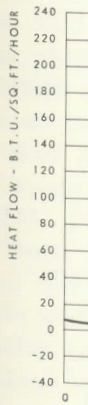

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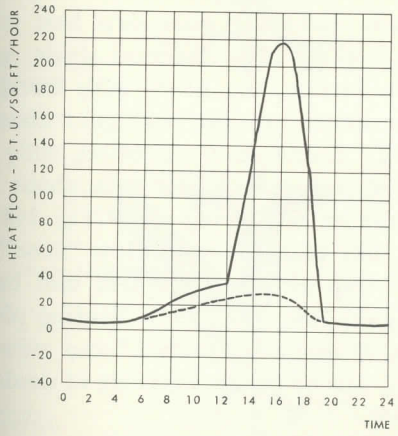
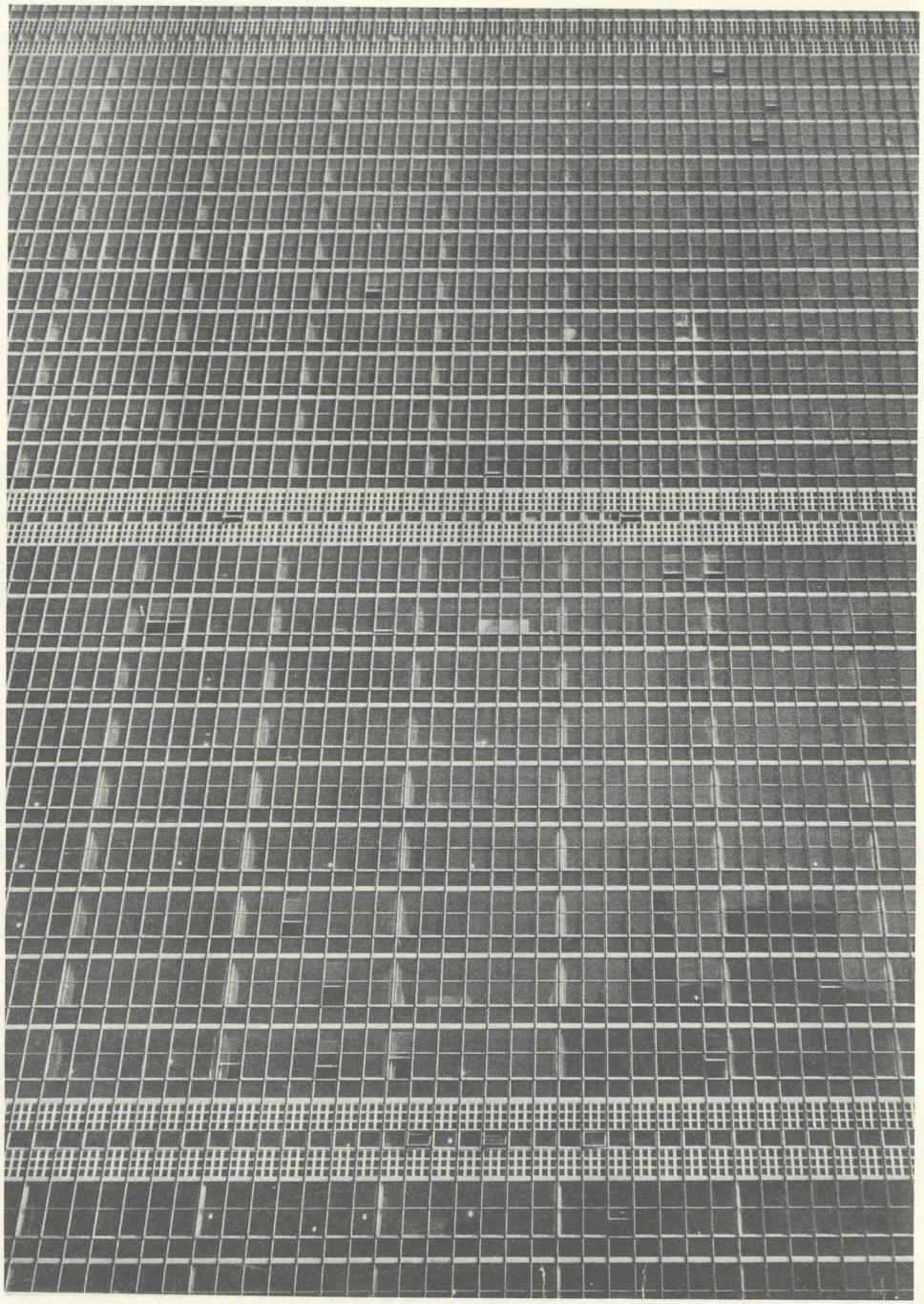
a wall consisting of a lightly painted insulated wood frame construction (U = 0.13). The other graph (Fig. 131) shows the heat transmission of a single glass pane. On the charts the hours of the day are indicated horizontally; the amount of heat flowing to the interior of the house is registered vertically. Note that the indication of flow for the glass is marked on a higher scale than that of the wall. The daily total heat transmission of the sunlit wall (solid line) amounts to 40 Btu/sq. ft., and to 27 Btu/sq. ft. in shade (dotted line). The daily total transmission of the sunlit glass pane is 1227 Btu/sq. ft., and it totals 346 Btu when shaded. In this case the glass is more than 30 times as vulnerable to sunlit conditions as the opaque wall. Also, through shading the glass, heat impacts can be reduced to one-third.

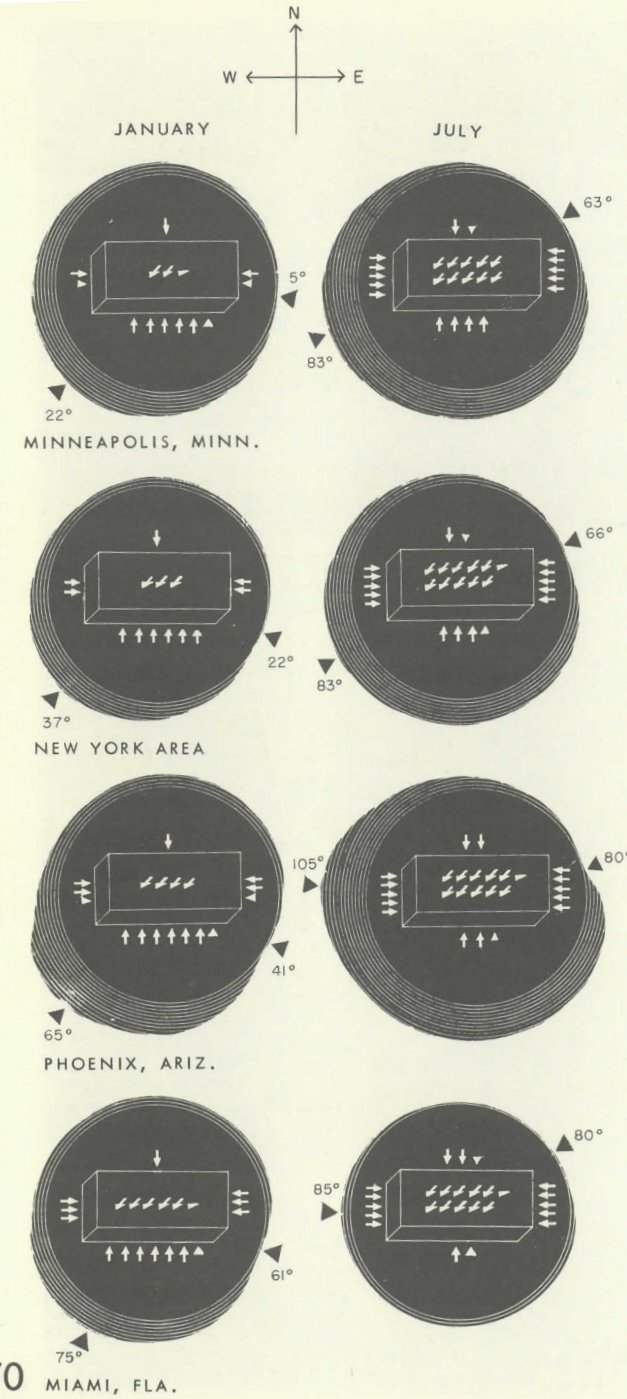
These vulnerability ratios differ according to latitude, orientation, time of the year and some other conditions. The protection of the glass surface depends mostly on the amount of radiation intercepted by the material itself, or by shading devices. These questions will be discussed briefly on the next pages.



131. Heattransmission of a glass pane.



132. Facade of the U.N. Secretariat, mid-twentieth century.



133. Impact of external thermal forces on buildings.

To compare the amount of thermal impacts on differently oriented surfaces, four cities were selected inside the boundaries of the U.S. approximately at the 24°, 32°, 40° and 44° latitudes. The figures (133) indicate average clear winter (January 21) and summer (July 21) days. The air temperature variation is indicated by the outside concentric circles showing average temperature fluctuations during the day. Each additional line represents a 2°F. difference from the lowest daily temperature. The direction of the impact is indicated according to the sun's direction as the temperatures occur. (Note the low temperatures at the east side, and the high ones in westerly directions.)

The total radiation impact on the various sides of the building is indicated with arrows. Each one represents 250 Btu/sq. ft./day. The radiation effect on the various sides of a building expressed in values of Btu/sq. ft./day is:

	Minneapolis	*New York*	*Phoenix*	*Miami*
WINTER				
East	416	517	620	734
South	1374	1489	1606	1620
West	416	517	620	734
North	83	119	140	152
Horizontal	654	787	954	1414
SUMMER				
East	1314	1277	1207	1193
South	979	839	563	344
West	1314	1277	1207	1193
North	432	430	452	616
Horizontal	2536	2619	2596	2568

These values show that from the thermal point of view the south side has a favorable relationship with the seasons, which effect is more pronounced at the lower latitudes. East and west are less advantageous, and of the two the west is more dangerous, due to high temperatures coupled with the radiation effects. North sides receive relatively small amounts of radiation, while a horizontal surface receives the maximum impacts in summertime.

Different glass materials and arrangements admit light and shut out sun heat with varying effectiveness. The heat-flow diagrams on the opposite page illustrate some of these arrangements based on west-facing glass at 3 P.M. on a standard "design day" of Aug. 1, at 40° north latitude. All figures are in degrees or in Btu's on a square foot per hour of vertical west surface. Except for the first diagram, all show heat gain for a city's "industrial atmosphere."[49]

Instantaneous heat gain through ordinary glass is 210 Btu/sq. ft./hour; direct solar transmission, over 88% (Fig. 134). Regular plate glass absorbs considerable radiation, helps to cut total heat gain to 144 Btu/hr (Fig. 135). Heat-intercepting plate glass (light color) transmits less than 40% of sun heat, cuts total heat gain by more than 25% (Fig. 136). "Darkening glass," while non-selective, cuts heat gain over 30%, reduces transmitted light to one-eighth of original value (Fig. 137). Double glazing, with the outer sheet of heat-intercepting plate glass, reduces total heat gain 45% because of insulating air space (Fig. 138). Gold coating on regular plate glass, plus protective heat-intercepting layer, reflects 42% of energy, cuts heat gain 50% (Fig. 139). Directional glass block admits 48% as much heat as regular plate glass, bends light against ceiling (Fig. 140). Double glass, outer pane darkening glass, cuts heat transmission 59% (Fig. 141). External shade made of dark heat-intercepting glass, with freely ventilated air space, can cut heat gain about 59% (Fig. 142). Inside shade or blind, fully drawn and closed, can reduce heat gain about 50% if truly white on side facing glass (Fig. 143). Ideal shading, like that of overwindow "hood" which does not trap air or reflect heat into building, reduces gain 70% (Fig. 144). Shading plus double glass, if similarly "perfect," can reduce heat gain 80% due to insulating effect of double glass (Fig. 145).

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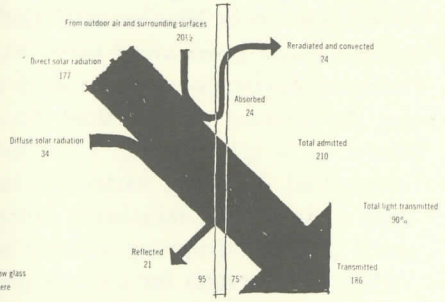
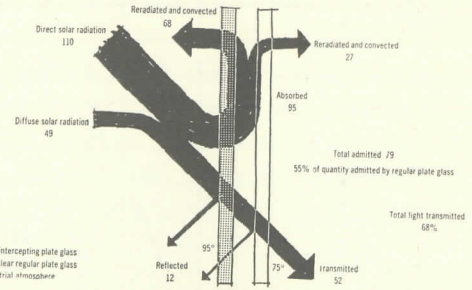
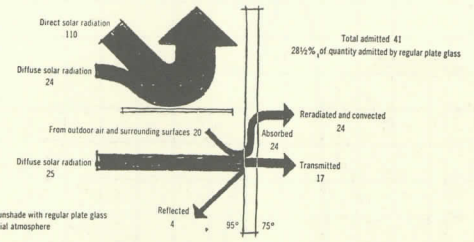


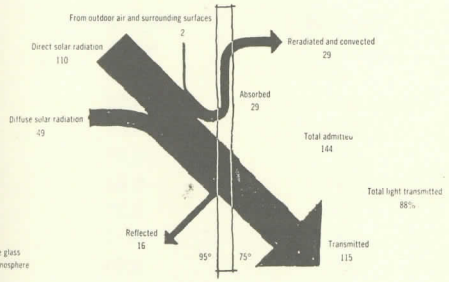
134 Ordinary window glass
Clear atmosphere



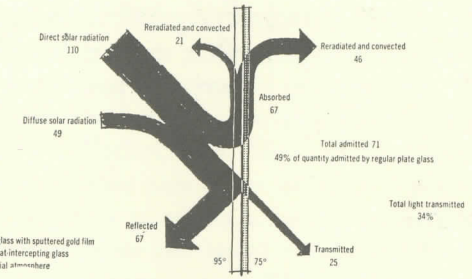
138 Heat-intercepting plate glass
plus clear regular plate glass
Industrial atmosphere



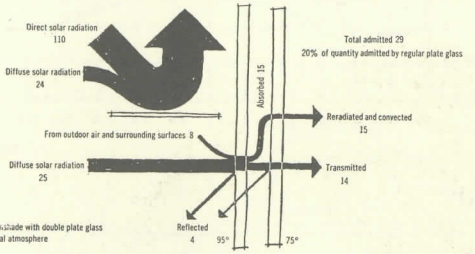
142 Ideal sunshade with regular plate glass
Industrial atmosphere



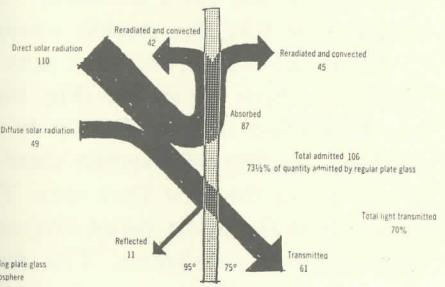
135 Regular plate glass
Industrial atmosphere



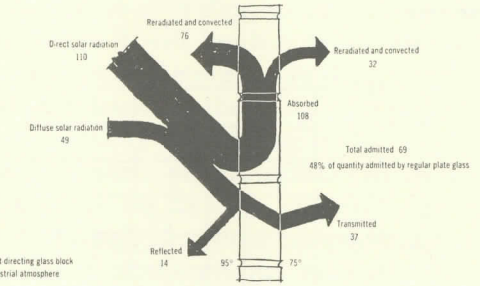
139 Plate glass with sputtered gold film
plus heat-intercepting glass
Industrial atmosphere



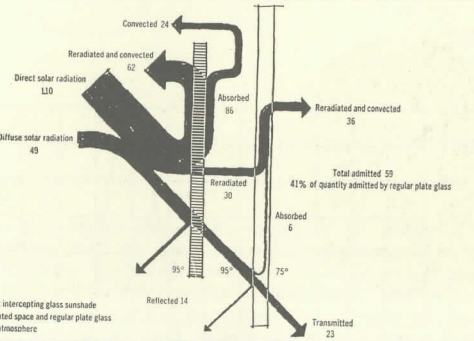
143 Ideal sunshade with double plate glass
Industrial atmosphere



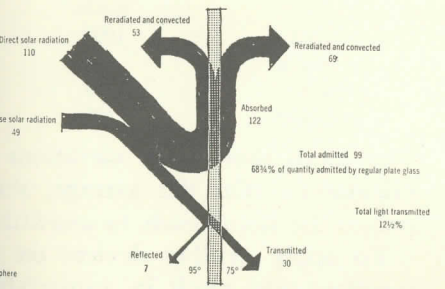
136 Heat intercepting plate glass
Industrial atmosphere



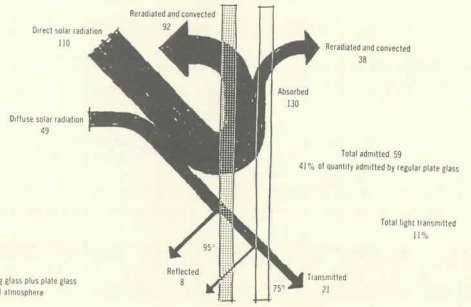
140 Light directing glass block
Industrial atmosphere



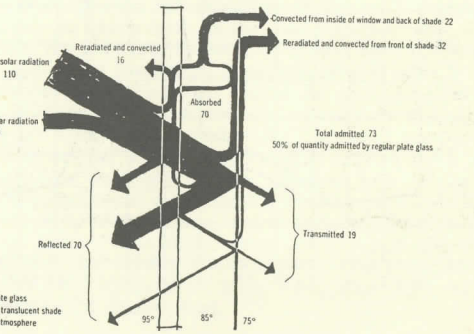
144 Dense heat intercepting glass sunshade
with ventilated space and regular plate glass
Industrial atmosphere



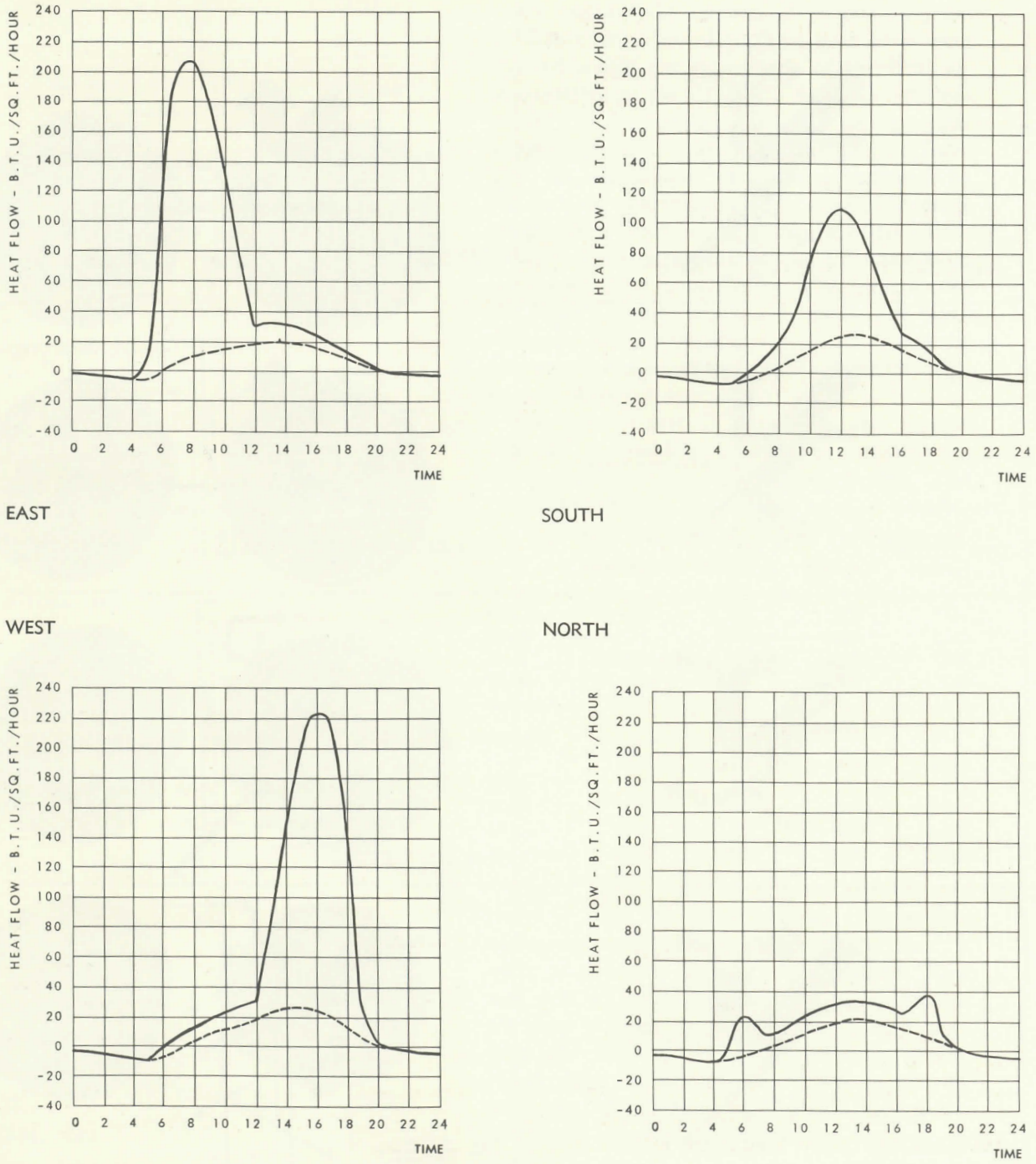
137 Darkening glass
Industrial atmosphere



141 Darkening glass plus plate glass
Industrial atmosphere



145 regular plate glass
plus white, translucent shade
Industrial atmosphere



146. Heattransmission charts for differently oriented wall surfaces.

The foregoing pages of this chapter discussed the difference in heat transmission between an opaque and a transparent material, the external radiation impacts on various sides of a building, and the amount of heat flow through different glasses at a given time. The direct radiation transmitted, however, varies markedly with the angle of incidence, remaining fairly steady until about 50° but dropping sharply after 60°.

Here are the data for a single glass (with 0.90 transmittance at normal incidence) and a double glass ($T_n = 0.81$) window:

angle of incidence	single glazed window	double glazed window
0°	0.90	0.81
20°	0.90	0.81
40°	0.89	0.80
50°	0.87	0.77
60°	0.82	0.71
70°	0.77	0.59
80°	0.44	0.29
90°	0.00	0.00

The transmittance of diffuse radiation is independent of the sun's position; (for the above single glass 0.82, for double window 0.72).

As a summation of the heat transmission problem, charts are shown (Fig. 146) illustrating the flow effect of four differently oriented glass surfaces, during an average clear summer day (July 21) in the New York area. The graphs indicate both the sunlit (solid line) and the shaded (dotted line) conditions. The daily total Btu flowing through a square foot of single glass surface is as follows:

	Sunlit	Shaded
East	1097	134
South	601	138
West	1097	134
North	305	123

The totals show large variations according to orientations. On the average, shading devices reduce the sunlit loads to one-fifth in this area.

To apply shading devices on an elevation, therefore may result in appreciable economies.

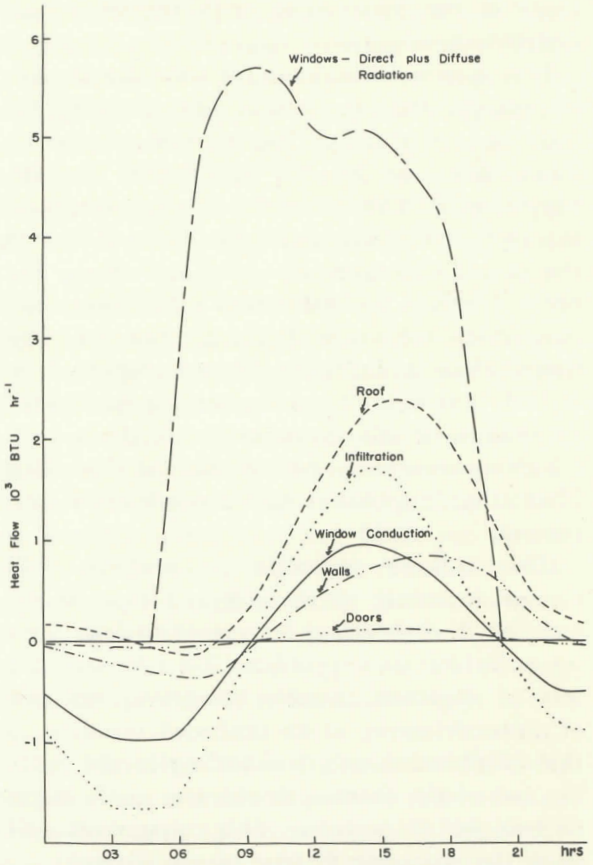
XIV. ECONOMY OF SHADING DEVICES

ONE is conscious of the difficulty in presenting generalities which concern economic values of different types of sun-shades in various orientations, locations and types of buildings.

Nevertheless the question arises: do they pay their way in reducing cooling loads, or are they merely a new kind of architectural decoration?

The functions of the devices are interrelated; their esthetic role, to provide a "sculptured" exterior, is as old as architecture itself. They can be used as access galleries, or balconies, when their functional purpose is divided. But their main role is to act as a spatial insulator against the sun's radiation, and they will be discussed below only from this point of view. This role, as an insulating panel on a curtain wall, is rather different from the usual insulators, because it has elastic characteristics. The insulation value of a device changes according to the position of the sun, and so according to the seasons. With proper design it will insulate in the overheated period and let in the sunrays in the underheated period. A balance can be achieved therefore between the cooling and heating loads.

The importance of sun control can be shown by comparing the amount of heat entering a building through its various components. Curves can be made of the diurnal variation of heat-flow through unit areas of differently oriented building elements. Total heat transmitted into a building can then be calculated by summing up the products of the unit transmissions and the appropriate areas involved. Applied as an example to a standard house of conventional wood-frame construction, Fig. 147 shows the total heat flow through its various components on an average summer day in July in the New York-New Jersey area. From the figure conclusions can be drawn about the relative impor-



147. The figure shows the result of an analysis of the heat flow through the various components of a typical single story residence structure.[51] A conventional low cost house was selected as an example. The importance of the winter heating period in the climate of the New York–New Jersey area, where the house was assumed to be located, limited the selection of the wall and roofing materials to those with a low heat-conductivity. Consequently, the building consists of frame construction with wood siding on insulating board sheathing with 2 inches of mineral wool insulation and a ⅜ inch gypsum board inner surface. The roof consists of asphalt shingles (absorptivity to Solar radiation = 0.7) on solid wood sheathing. The ceiling of gypsum board is backed by 3 inches of batt-type insulation. The windows are of ordinary (type B) glass with a transmittance for solar radiation of 0.77 at normal incidence, set practically flush with the exterior wall. Half-drawn, dark-colored pull shades are assumed to be behind the windows. The total effective areas of this house are: walls 866, roof 768, windows 139, doors 38 square feet.

tance of the components with respect to undesirable heat gains.

It is apparent here that the windows account for the greatest amounts of heat entering the building and therefore the method of shading them offers the greatest opportunity for improved performance. Second in importance is the roof, and third comes the infiltration and the window conduction. Wall materials and opaque vertical enclosures play a relatively small part in comparison with the components mentioned above unless they are not properly controlled. It is well known that only a synthetized integration of all components will result in a "climate balanced" shelter; nevertheless, this illustration emphasizes the importance of sun control.

This relative importance, naturally, will change according to the size and type of the building, and therefore a separate analysis must be made for each problem. To take another way of approach, namely comparing the cost of air-conditioning of an unshaded building to that of a shaded one, and adding to the latter the cost of the shading device, the result might be positive or negative. This comparison will show the economic balance of the device.

For design purposes this process can be reversed. Knowing the sun's heat entering through a unit surface, and the cost of the air-conditioning necessary to counterbalance this amount, the cost of a device which will break even economically can be determined. Thus a design criterion can be established.

One ton of refrigeration equals 12,000 Btu per hour. This equals a heat load that may fall on 100 square feet of easterly or westerly oriented walls. If this load is cut off, one ton of air-conditioning capacity can be saved, for each 100 square feet of wall.

In the New York area from direct sun radiation a single glass surface on July 21 on a clear day will transmit into the building in Btu's per square foot:

	ORIENTATION		
	East	South	West
5 a.m.	23	...	...
6 "	126	...	...
7 "	177	...	...
8 "	185	2	...
9 "	160	19	...
10 "	108	45	...
11 "	43	58	...
12 Noon	...	72	...
1 p.m.	...	58	43
2 "	...	44	108
3 "	...	19	160
4 "	...	2	185
5 "	...	...	177
6 "	...	...	126
7 "	...	...	23

The cost of air-conditioning can be estimated as:

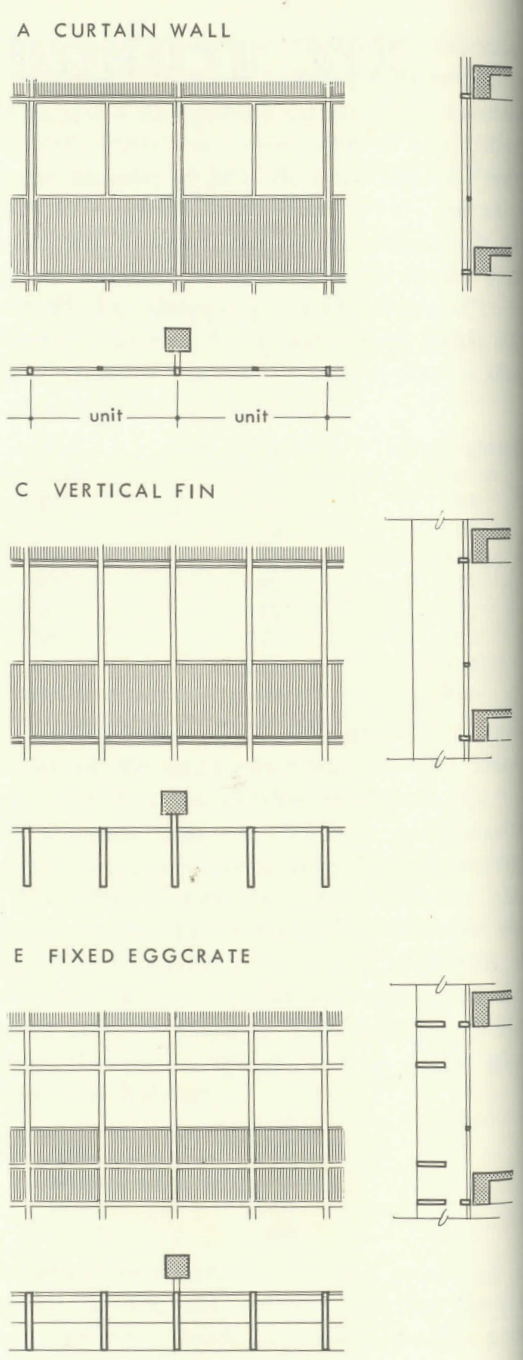
A. Installation cost, where one Btu of air-conditioning varies between $.05 and $.07. (Prices quoted in these pages are as of 1956.)

B. Operating cost, which runs around 5% of the installation cost per year.

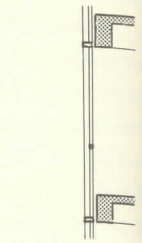
From the instantaneous heat-gain there is still the question of transforming this value to cooling-load. It has been realized that, due to storage effect and lag, not all of the peak heat-gain to a structure would appear as an instantaneous and simultaneous peak cooling-load. Some take the average of the three maximum hours of heat-gain as peak cooling-load. Some take 70% of the peak heat-gain. Following these methods, and taking their mean values, the peak cooling-load, in the New York area from the direct sun radiation, which could be saved by 100 percent shading, in Btu's per square foot:

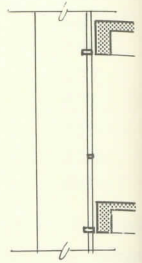
	East	South	West
Saveable cooling load	157	57	157

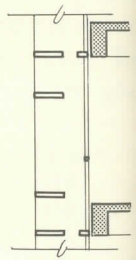
The above figures do not include diffuse radiation, which will also be cut out in part by the shading device.



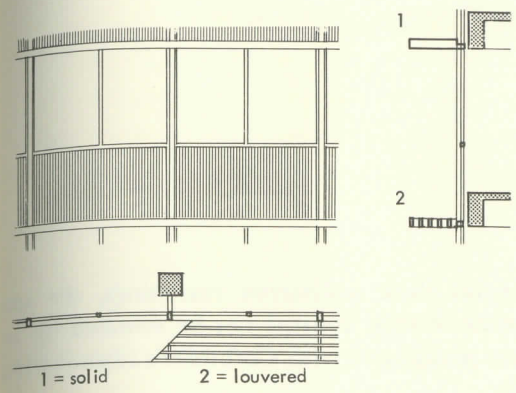
148. Standard types of shading devices.







evices.



Calculating the installation cost, and adding to it two years of operating cost, the savings in the air-conditioning cost by the device can be estimated, per square foot of window area, as:

	East	South	West
Possible savings:	$8.60-$10.40	$3.00-$3.80	$8.60-$10.40

Thus a "design criterion" can be established: a properly designed shading device will break even economically, if it costs as much as the above figures. If it costs less, it will save money. In practice the cost of shading devices is usually less than the figures quoted above.

Fig. 148 shows various standard types of devices in schematic diagrams. The first, "A," is a curtain wall unit without any projection, for comparison purposes only, while "B"-"F" show different types of devices. The cost of a curtain wall "A" differs according to the type; if it is a closed wall or if it has openable windows. The cost of a fixed type varies between $3.50 to $4.50 per sq. foot, while the same with openable ventilating units varies from $4.50 to $7.00 per sq. ft. The additional cost of a horizontal solid shading device "B.1" is about $2.20 to $2.60 per sq. ft. of window surface, while a louvered type "B.2" is between $3.60 and $4.60. The cost of a vertical fixed device "C" is between $4.40 and $6.00, and a movable device "D" is between $8.00 and $10.00 per sq. ft. of window surface. Eggcrate types cost between $6.40 and $8.50 if they are fixed as "E" and if movable as "F," their cost varies between $8.00 and $10.50 per sq. ft. of window surface.

The horizontal shading device protects efficiently around southern orientations, while the other types work well toward the less favorable sides. The more expensive movable types might be utilized toward east, southeast, southwest and west.

It is evident that shading devices might not only pay their way, but save in cost, if they are properly designed.

Stevens and Wilkinson, architects of the Georgia Baptist Hospital in Atlanta (*see* Part 4) concluded: "To protect east, west and south windows of the hospital from solar radiation, an all-over grid is utilized consisting of concrete extensions of the floor slabs above windows, a cross-grid of louvers at the level of the meeting rail and vertical louver panels at the columns. This system saved in air-conditioning equipment considerably more than its cost and will effect 15 percent savings in operation. This system also effected a 30 percent saving in the cost of the air-conditioning installation."

In remodeling the Los Angeles Federal Savings Bank,[50] with aluminum louver screens, their cost was less than nothing, for the savings in air-conditioning installation was $6.00 per square foot of window wall, while the installation cost of louvers amounted to $4.00. Net installation savings above the cost of louvers was $2.00 per sq. ft., and the yearly saving in air-conditioning operation is estimated as 5 cents per sq. ft. in addition.

The Flintridge Office Building in Fairfield, Alabama has movable horizontal sunshades, of which the cost is approximately $107,000. Architects Holabird, Root, and Burgee estimate that the shades will reduce initial air-conditioning equipment by about $98,000; save another $16,000 because of the reduced building cost in circulation dimensions; and some $1,000 a year in operation costs.

Several examples could be quoted which show savings, or which break even; others, which show a negative balance in this utilitarian reasoning, can be justified because of other factors.

It is clear that savings can be achieved, but only with proper design, the importance of which cannot be over-emphasized. As shown above, varied orientations have different heat impacts. The counterbalance of the heat impacts will affect either the cost of the mechanical cool-

ing or that of the shading device. This calls for careful architectural design, where the steps to follow can be categorized as:

1. The arrangement of the whole building lay-out, determining the orientation of the elevations.
2. The size and distribution of the openings, which determine the heat transmission of the elevations.
3. The proper design of the shading devices, which will result in economy only if they work efficiently.

A few practical aspects should be added to the considerations above. Exterior devices may conduct heat into a structure on windless, hot days, especially if they are made of dull-finished materials. Conversely on windy, cold days they may carry heat away from the walls as a cooling radiator. This can be avoided, if the devices are insulated from the building. The simplest solution to achieve this is, not to connect the device along its entire length with the building, but only on necessary connection points, leaving an open airspace in between. (This open slot also serves as an escape hatch for banked-up warm air.)

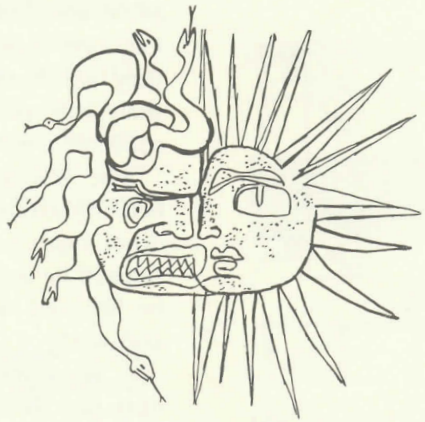
A further consideration is the snow and ice problem. In higher latitudes and on elevations facing streets or public areas this might create a hazard. Projecting the lowest horizontal overhang further out from the facade can solve this problem. Furthermore, Nature seems to have thought of this, and eliminated icing in the southern latitudes where elevations with depth are most useful.

The problem of maintenance is always present, with or without shading devices; its solution would seem to lie in the quality of architectural design which will encompass not only the shading problem but also that of maintenance as well.

Beyond these utilitarian reasonings, the importance of solar control can be summed up in proper perspective with Corbusier's illuminating words:

". . . the problem of the sun—as we know—is that it passes from one extreme to the other according to the change of the seasons. In this play many conditions are created which await adequate solutions. It is at this point that an authentic regionalism has its rightful place. The techniques are universal. . . . The sun differs along the curvature of the meridian, its intensity varies on the crust of the earth according to its incidence.

In this detail the Creator has given us beautiful and prodigious diversity. It is for us, in succession, to seek a solution which is worthy of the work of nature."



149. After Le Corbusier.

PART 3 PRACTICAL APPLICATION

XV. Summary of Method 78
Application of the Method in a Design Example 81
XVI. Charts and Diagrams 84
Vocabulary of Devices 88

XV. SUMMARY OF METHOD

IN the foregoing chapters theoretical considerations were described, resulting in a method by which shading devices can be evaluated or designed.

Here this method is repeated in a short summary for practical application. The numbers in the text refer to the chapters and pages where more detailed information can be obtained for the proceedings in question. After the description an example follows to illustrate the method in practical use. Finally, charts and diagrams are appended which, being at the same scale, can be used as underlays for evaluation purposes.

Designing a shading device, in a given situation, the following steps should be taken:

STEP 1: TO DETERMINE THE TIMES WHEN SHADING IS NEEDED.

During cool times of the year (called "underheated period") the warming effect of the sun is desirable. During warm times (called "overheated period") shade is needed to achieve or approach comfort conditions.

For practical use the 70° F. temperature can be accepted as a dividing line between these two periods (Chapter III, pp. 21-23). According to this, any condition which exceeds 70° in temperature falls in the category of the overheated period and provisions should be made for shading at these times. This is based on the conditions of the Temperate Zone inhabitants of the United States (Chapter III, p. 20), around 40° N. latitude. Inhabitants of lower latitudes are acclimatized to warmer conditions.

Hence on every 5° latitude change toward more southern locations in the United States the temperature line, where the shading need begins, should be elevated by ¾° F.

To define the times when shading is needed, data should be collected concerning the daily temperature changes throughout a year at the place in question. Average daily temperatures should be used with hourly or two-hourly data for each month of the year. The temperatures, which fall over the dividing line (70° in the Temperate Zone) will define the overheated period, or the times when shading is needed.

This can be conveniently tabulated on a chart, where the hourly and the monthly divisions serve as ordinates. On this chart the overheated period can be outlined as an area. The times when shading is needed are defined by this area, which will change in configuration in various locations, where different climatic conditions are likely to prevail (Chapter III, p. 23; p. 86).

STEP 2: TO DETERMINE THE POSITION OF THE SUN, WHEN SHADING IS NEEDED.

A. This can be done with the use of the "sun-path diagram," (Chapter VII) which shows the sky-vault projected on to the horizon plane. On the diagram the horizon line appears as a circle at the outside edge, and the sun-paths as curved lines. These lines designating days and months of the year represent the sun's path on the dates shown. Connecting lines indicate the hours, and between the hour lines are lighter lines indicating twenty-minute intervals. The sun's position can be determined at any time with the use of this diagram: its bearing angle from the south point on the perimeter of the diagram, and its altitude angle with an equally graduated scale from the center point (Chapter VII, page 40).

B. The sun-path diagrams will change accord-

ing to the location (latitude) of the place in question. Diagrams are shown, for each four degrees of latitude from 24°-52° (Northern hemisphere) on pages 84, 85. The diagram which is nearest to the latitude of the location of the place under investigation should be used.

c. The sun-path diagram is used as a chart to transfer the overheated period, where the months and hour lines serve as coordinates. The diagram will then not only show the position of the sun, but indicate also whether shading is desirable or not at a given time.

By the nature of the diagram, each line represents two dates when the sun has the same path during a year (Chapter VII, p. 41). Therefore, the overheated period as plotted includes points at which shading is needed on only one of the dates and sunshine is needed on the other. For the remainder of the diagram, sun radiation is needed on both dates. Sun-path diagrams with plotted overheated-periods are shown on page 87, for four typical climate regions.

STEP 3: TO DETERMINE THE TYPE AND POSITION OF A SHADING DEVICE WHICH WILL INTERFERE BETWEEN THE SUN AND THE POINT OF OBSERVATION DURING THE OVERHEATED PERIOD.

A. Shading devices can be plotted in the same manner as sun-paths on a diagram with the projection of the surface they cover on the sky vault as seen from the center of the diagram, as the point of observation (Chapter VIII, p. 45). The surface which they cover will represent those parts of the sky vault from which no sunlight will come. If the sun passes through such an area, the observation point will be shaded.

B. Any building element will define a characteristic form in these projection diagrams, which are called "shading masks." Masks of horizontal shading devices (overhangs, etc.) will show a segmental character, those of vertical fins will have a radial pattern, and eggcrate types, which are basically a combination of horizontal and vertical devices, will show a combination of these forms (Chapter VIII, pp. 48, 49). A mask can be drawn for any shading device, even for very complex ones, by simple geometrical methods. A protractor serves to plot any horizontal or vertical device, as shown in the mask categories (pp. 88-92) or with the examples, Part 4.

C. Overlaying a shading mask in the proper orientation on the sun-path diagram, one can read off immediately the times when the sun's rays will be intercepted.

With the overheated area plotted on the sun-path diagram the shading mask is superimposed, and it can be seen to what extent the unwanted solar radiation will be intercepted by the device. Performance of a given device can be evaluated by the effectiveness with which its shading mask covers the overheated period area.

D. For design purposes, the process can be reversed. Knowing the overheated-period diagram, one can determine the needed shading mask and then find the proper shading device for it. The shading mask should cover as much as possible of the indicated overheated period while taking care not to cover too much of the underheated one, when sunshine is needed. Efficiency of a shading device depends on the proportionate success with which it covers the overheated area without covering the underheated area. Limits of useful overhangs or other devices can be defined by such calculations (Chapter XII, pp. 64-67).

E. Masks can be drawn for 100 percent shading, in which case the total wall surface is in shade, and for 50 percent shading, when only half of the surface is in shade. The method of drawing these masks is amply illustrated in the examples, Part 4. If not entering into efficiency calculations, as a rule of thumb, it can be said that if the 50 percent border of a shading mask covers the outer perimeter of the indicated over-

heated-period area, the shading device will be effective.

Since, speaking of the Northern Hemisphere, the sun's path on the diagram shows segmental characteristics around the southern orientations, and radial ones towards the east and west, general rules can be deduced for the types of devices to be used toward different orientations.

Toward the south, and around southern orientations, horizontal shading devices work efficiently.

Toward east and west, and near these orientations vertical devices serve well. If slanted, they should point toward the northern directions, thus giving more protection from the southern positions of the sun.

Toward southeast and especially southwest, and around these orientations, the eggcrate type works well. Because of this type high shading ratio and low heat efficiency, its best use is in hot-climate regions.

Toward north, fixed vertical devices are recommended but their use is needed only in hot regions. In very low latitudes (under 23°) horizontal devices work well also toward this orientation.

For movable devices the same types can be recommended as for the fixed ones toward the different orientations. Their best performance can be utilized where the sun's altitude and bearing changes rapidly: toward east, southeast, and especially, because of the afternoon heat, toward southwest and west.

STEP 4: TO DESIGN A SHADING DEVICE FROM THE SHADING MASK.

With the previous steps, by the use of the sun-path diagram with the plotted overheated period, the proper overlapping mask can be determined. The mask will define the type and angle of the shading device. This angle, which determines the ratio of the depth of the device to the proper dimension of the wall surface, does not define a scale. A very small-scaled device, as an outside Venetian blind, will give the same shading effect as a balconied apartment house, provided that their proportions are the same. Since many devices, different in appearance, might have the same shading mask and therefore the same shading characteristics, there will be many possible solutions for each situation.

This enables one to tabulate different locking devices into categories, according to their similarity in shading masks. With this categorization a vocabulary of shading masks can be developed for design purposes. Some of the types, tabulated into three categories, are shown on pages 88-92. It would be an infinite task to show all types, but this table illustrates the various characteristics of typical devices. Many further combinations of shading devices are possible, as illustrated in some of the examples in the last part of the book.

To choose between the various technically correct possibilities, or develop new variations is the designer's task. This is the line where the technical method ends and creative expression takes over.

APPLICATION OF THE METHOD IN A DESIGN EXAMPLE

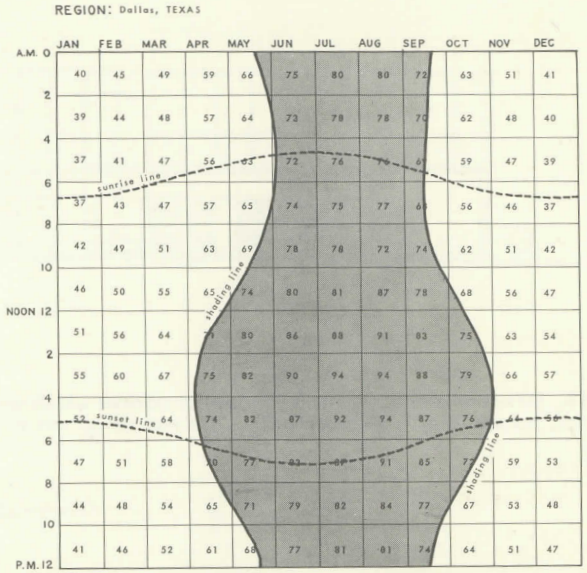
ALADAR OLGYAY, *Factory for Universal Corporation, Dallas, Texas*

The functions of this building were separated into two distinct parts: the manufacturing plant and the office part. The plant was treated as a box, with artificial illumination and conditioning, while the office part with its large windows facing almost north and south had to be equipped with shading devices. In designing these the following steps were taken:

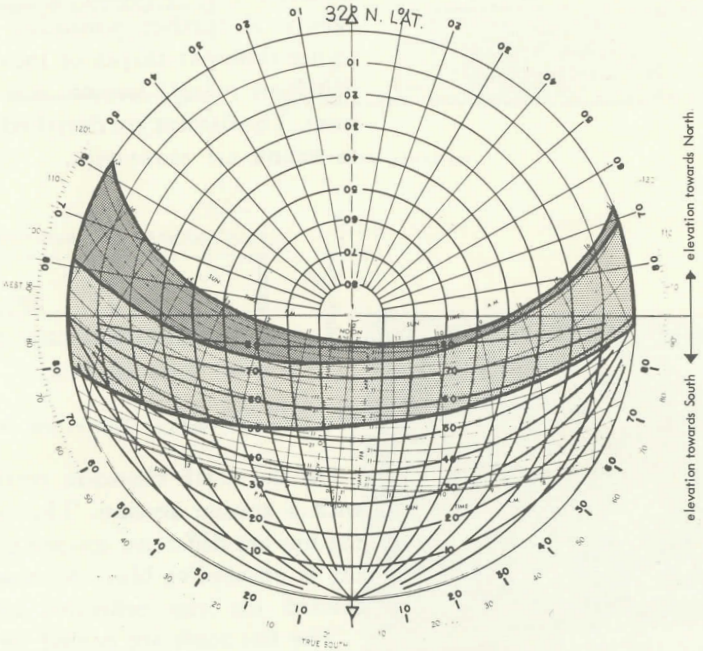
STEP 1 : TO DETERMINE THE TIMES WHEN SHADING IS NEEDED. A yearly chart was drawn up and the overheated period outlined on it; the times when shading is needed (Fig. 150).

STEP 2 : OVERLAY. On the nearest sun-path diagram (32° N. latitude) the overheated period was transferred and the protractor overlaid (Fig. 151). It is evident, that on the south elevation the segmental lines (horizontal device), and on the north the radial lines (vertical device) cover the overheated period most effectively.

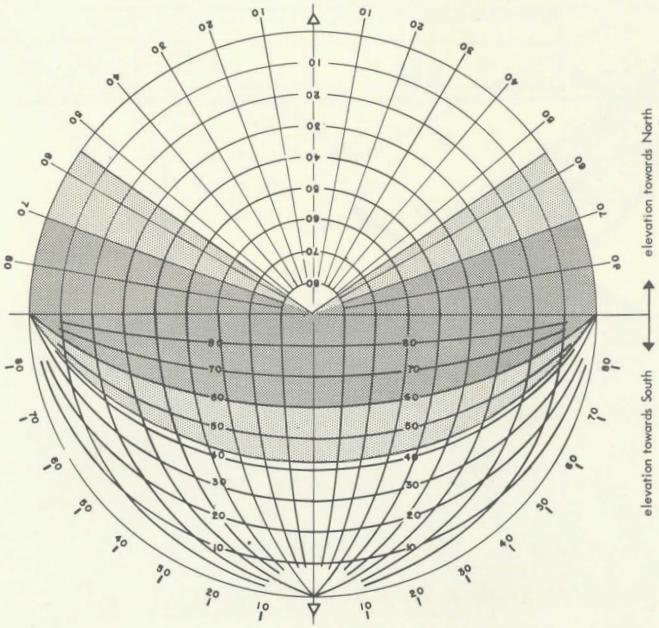
STEP 3 : TO DETERMINE THE ANGLES OF THE DEVICES. On the south elevation a 60° horizontal device and on the north a vertical one at a 20° angle measured from the wall, will be satisfactory. The 100% and 50% masks are shown in Fig. 152.



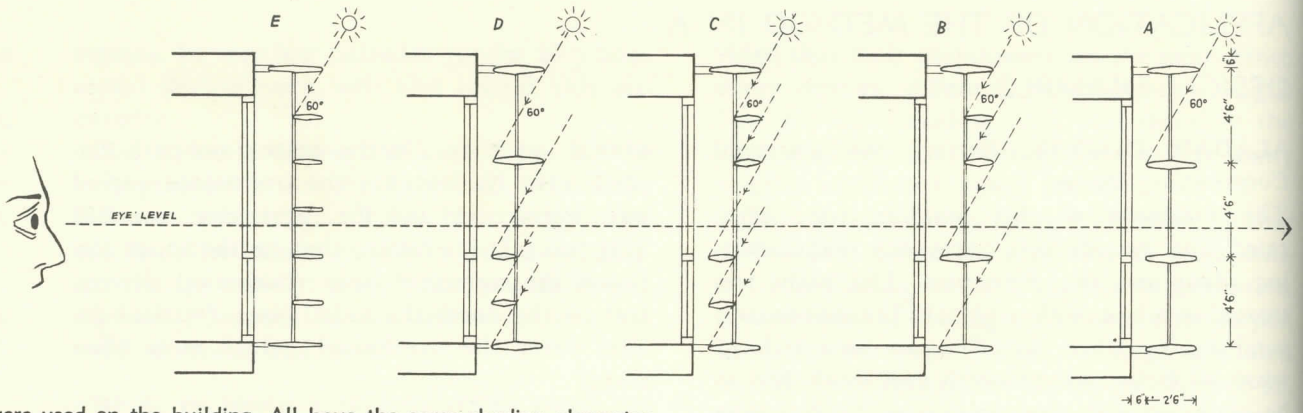
150. Yearly shading chart of Dallas, Texas.



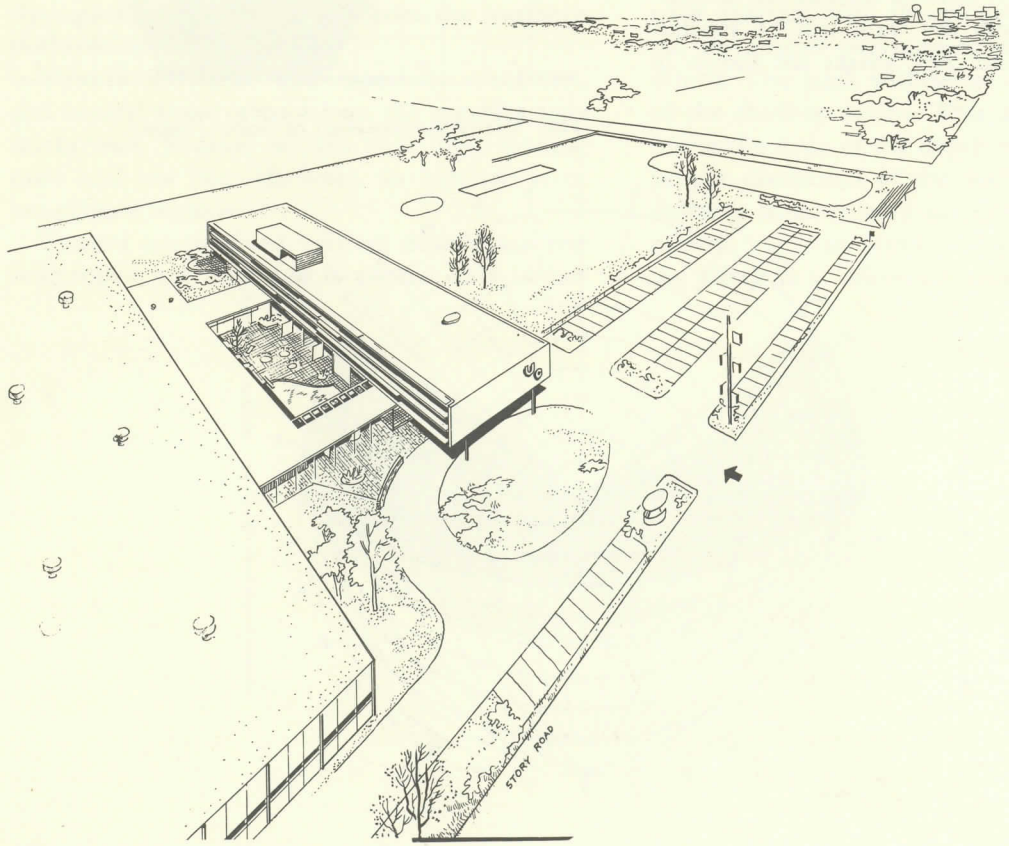
151. Overheated period transferred to sun-path diagram.



152. Shading masks for south and north elevations.

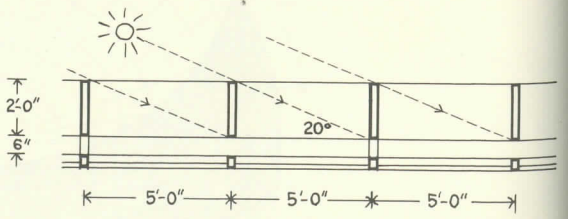


153. Different arrangements of horizontal devices which were used on the building. All have the same shading characteristics, namely a 60° altitude angle. Care was taken not to interrupt the eye-level vision line.



154. Aerial view showing the southern elevation.

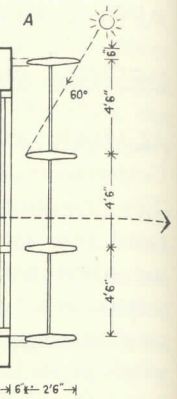
STEP 4: TO DESIGN SHADING DEVICES FROM THE SHADING MASKS. The mask defines the type and the angle of devices only, and possibilities remain for various design arrangements. In Fig. 153 sections are shown, which were used on the south elevation to provide a playful diversity. A further possibility would have been to use different shapes or louvered units, but an "airplane wing" section was chosen of aluminum. The devices are detached from the elevation to secure air movement.



155. Plan of vertical fins on the north elevation.

On the north elevation vertical fins were used with a similar section. The vertical surfaces of the fins are different; toward the west their coloring is absorptive blue to avoid reflection, while toward the east reflective aluminum is used.

The flat roofs are cooled by evaporation: two inches of water surface covers them, which depth is maintained by an electric water-pump.



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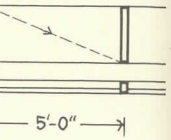

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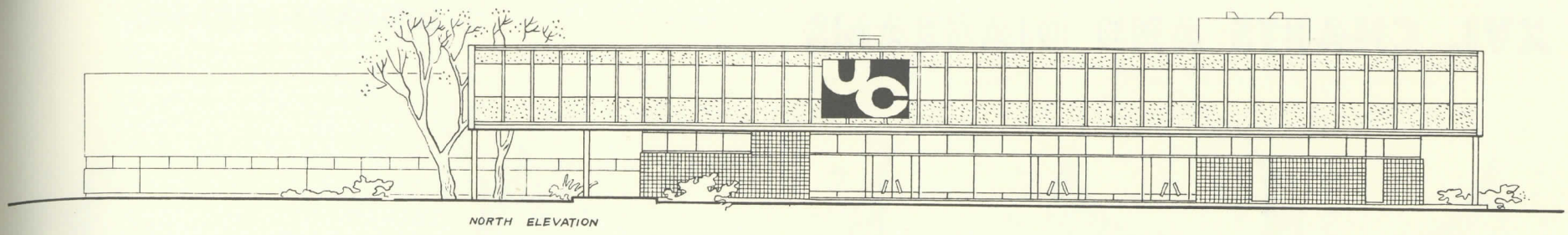
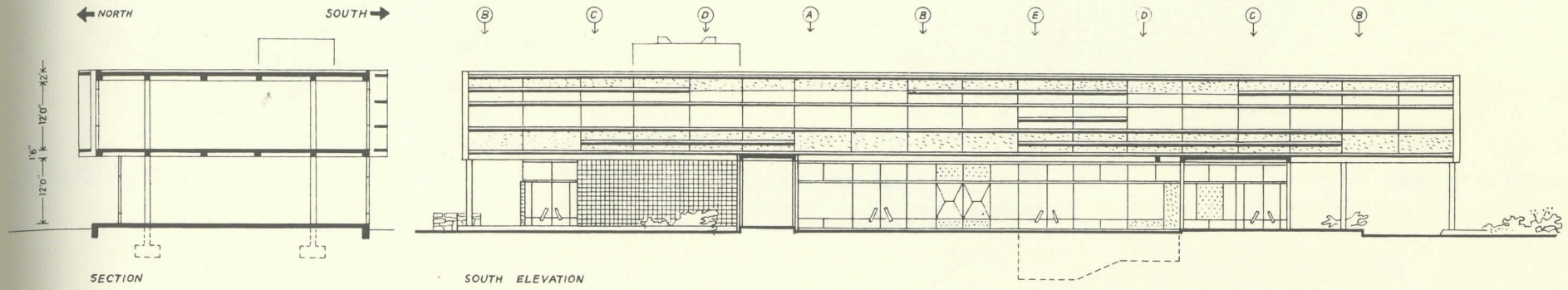
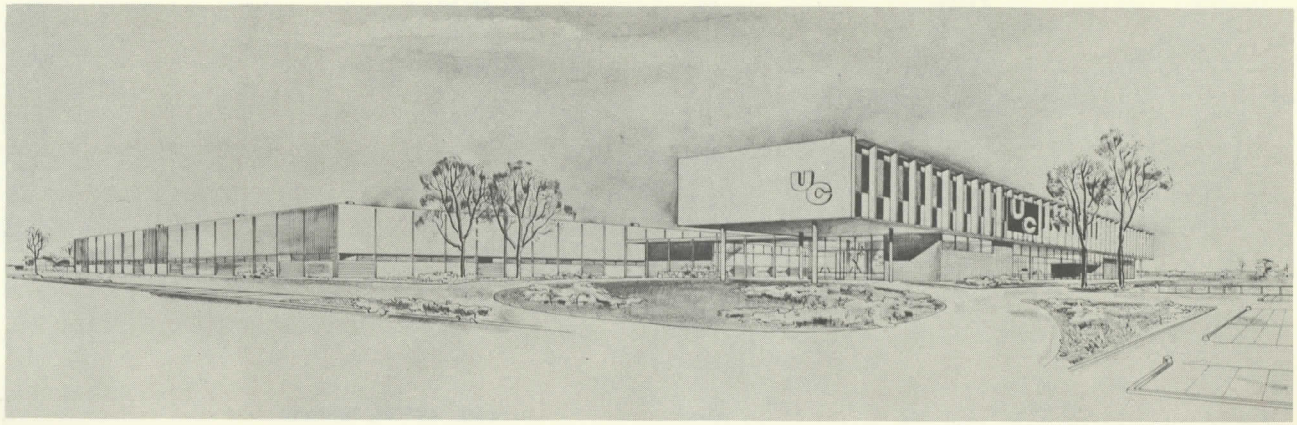


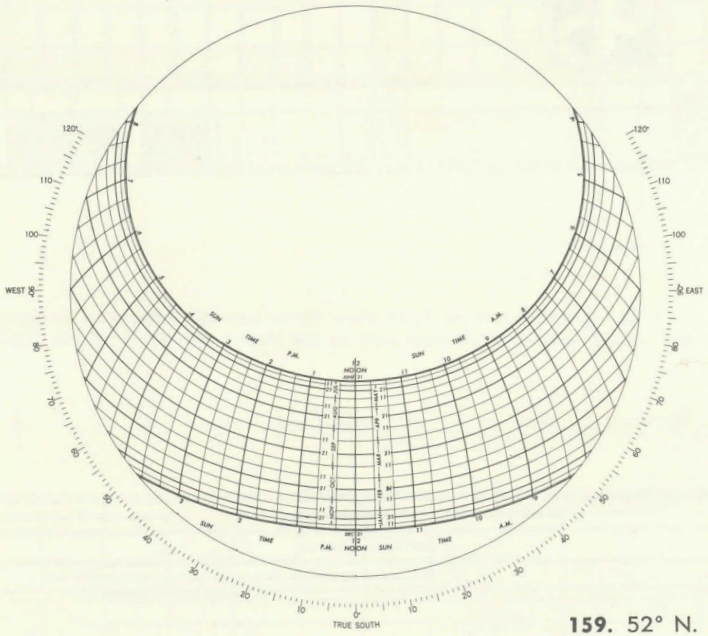
156. North elevation of office part.



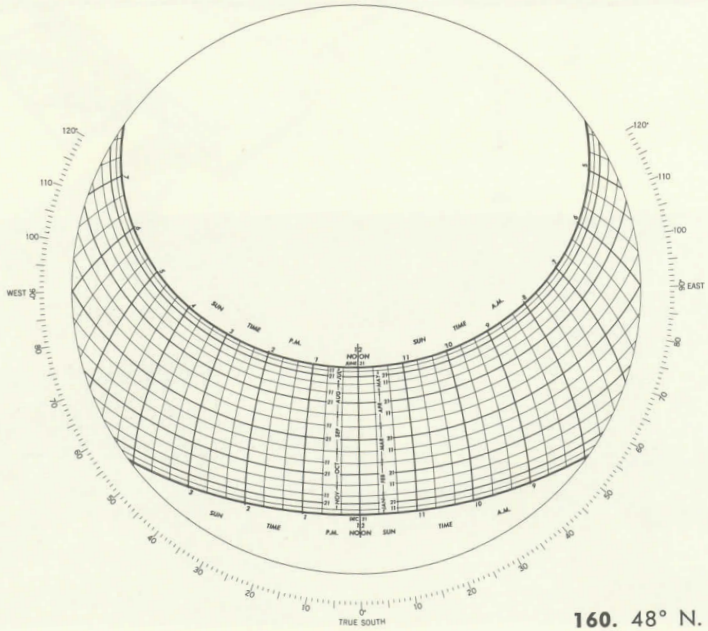
157. Section and south elevation of office part.



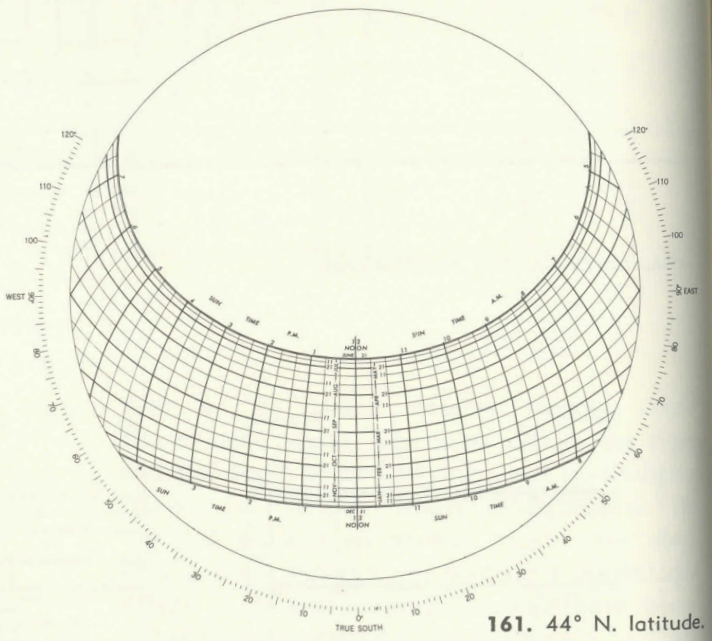
158. View of the entrance side of the building.



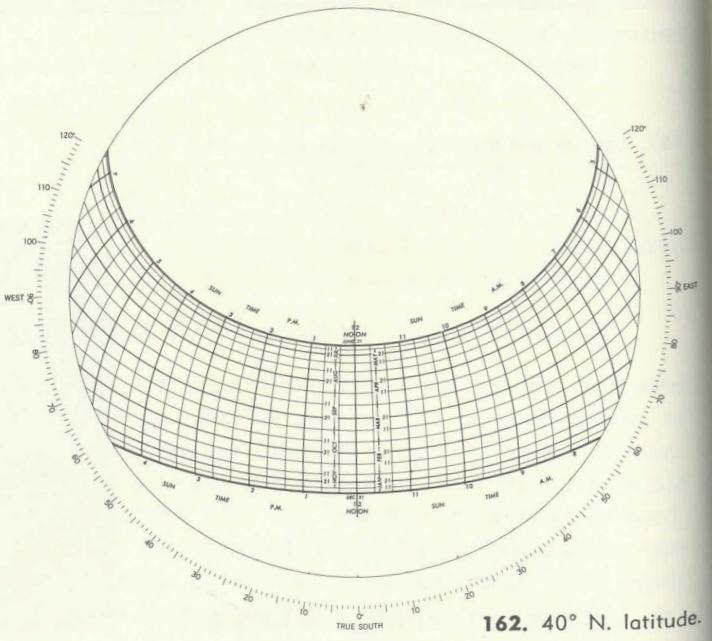
159. 52° N. latitude.



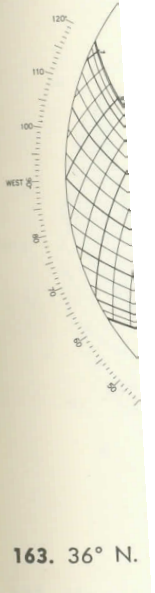
160. 48° N. latitude.



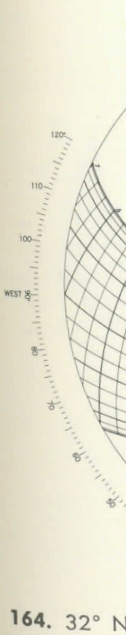
161. 44° N. latitude.



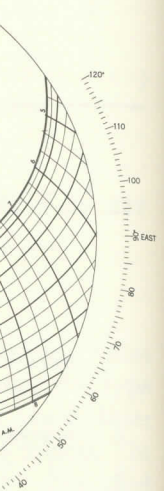
162. 40° N. latitude.



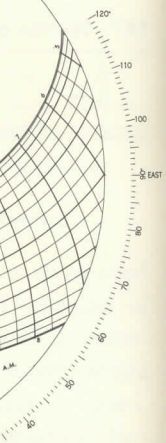
163. 36° N.



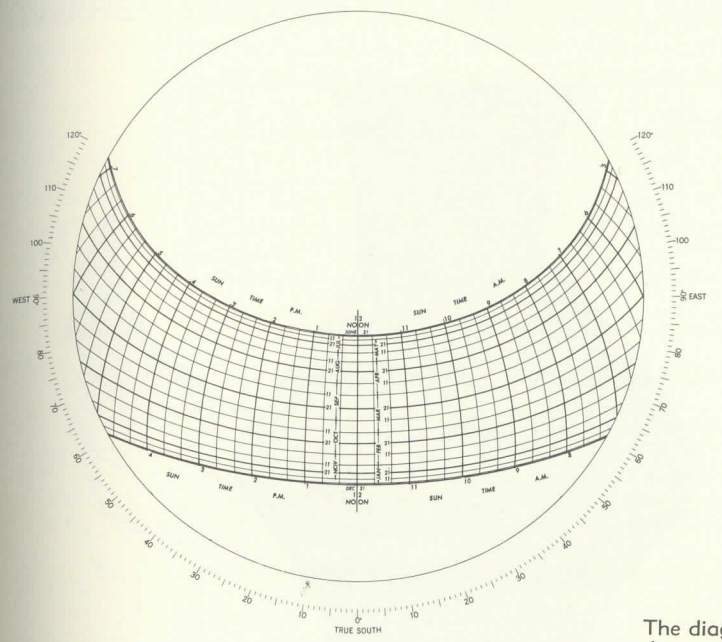
164. 32° N



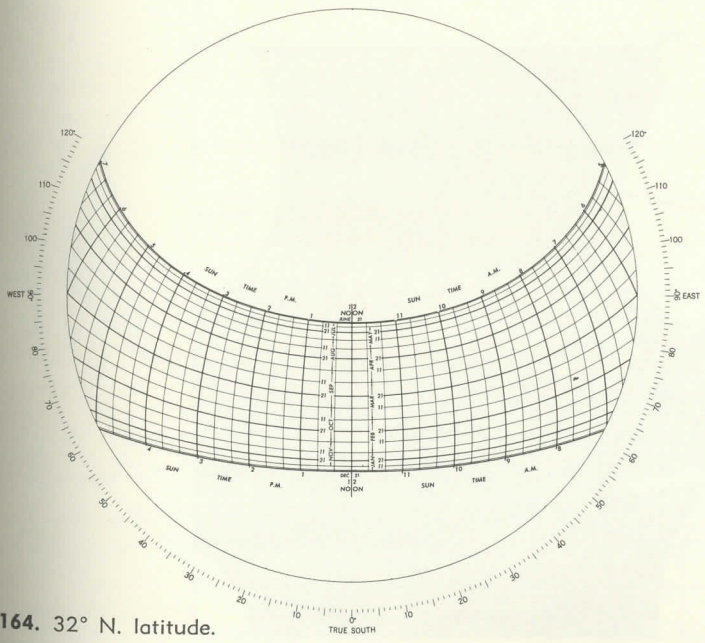
44° N. latitude.



40° N. latitude.

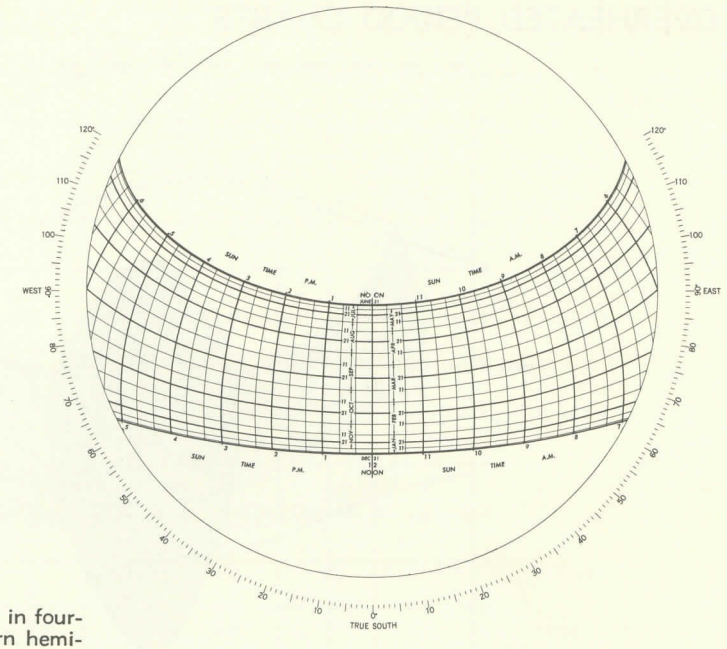


163. 36° N. latitude.

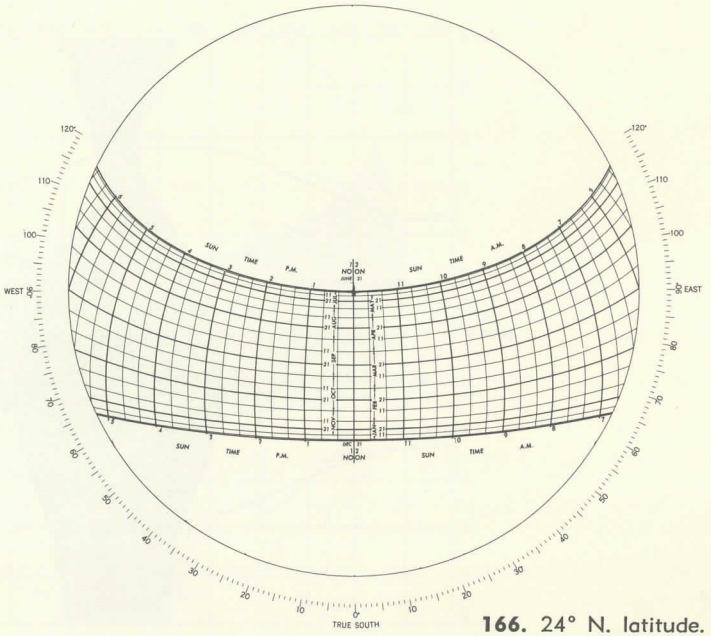


164. 32° N. latitude.

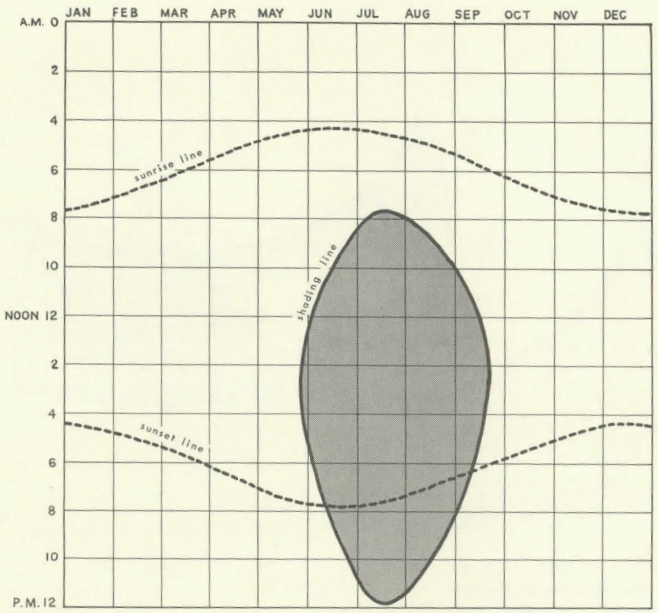
The diagrams cover the latitudes from 52° to 24° in four-degree intervals. All are oriented for the northern hemisphere, but can be used for the southern by changing the compass points. They are in equidistant projection, based on the "Sun Angle Calculator" (p. 27), and reproduced by the courtesy of the Libbey-Owens-Ford Glass Co.



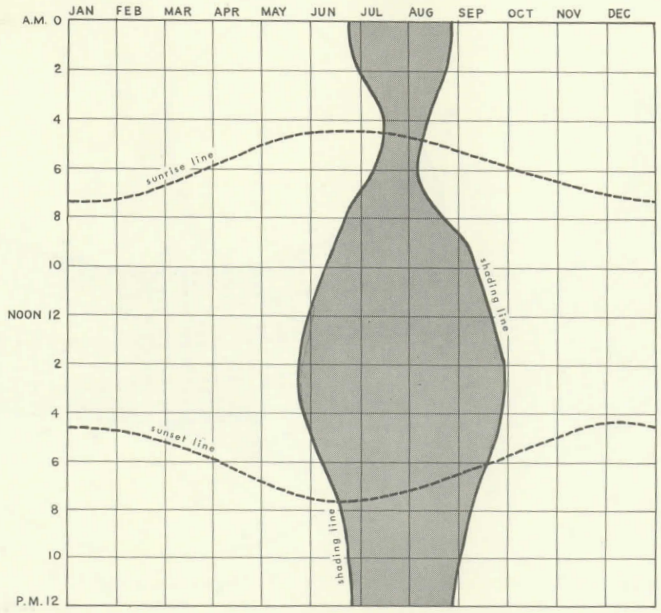
165. 28° N. latitude.



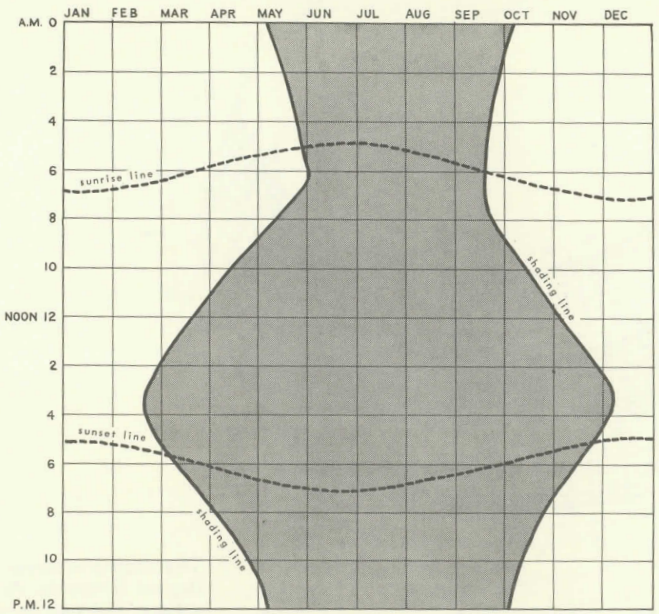
166. 24° N. latitude.



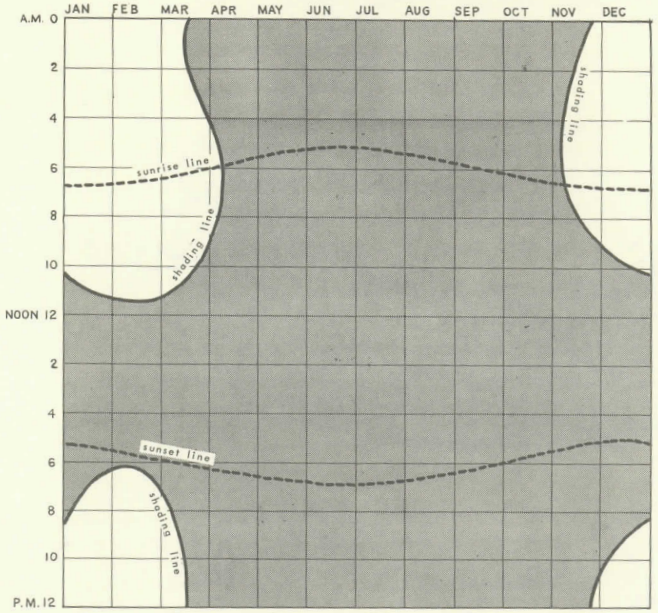
167. Minneapolis, Minnesota, 44° N. latitude.



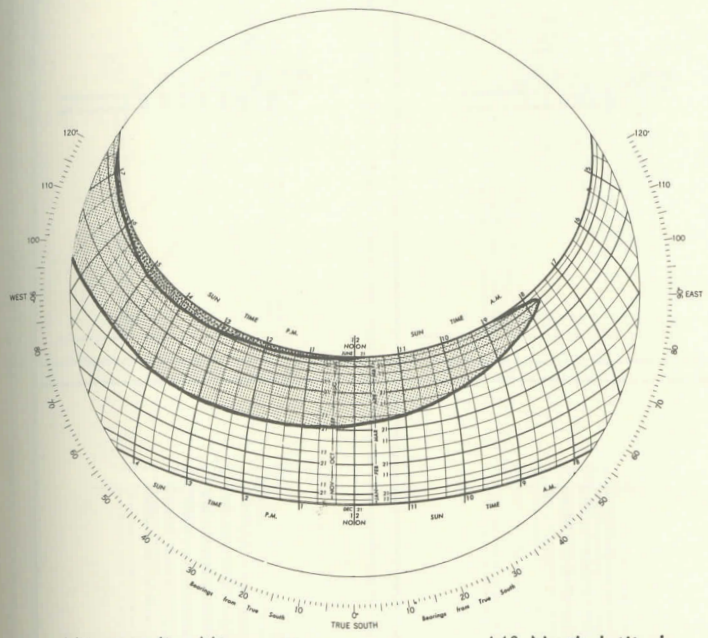
168. New York-New Jersey area, 40° N. latitude.



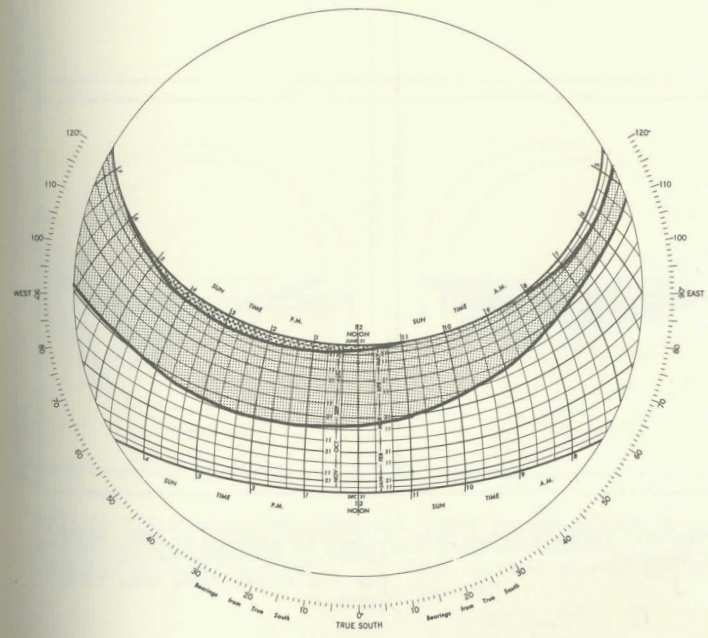
169. Phoenix, Arizona, 32° N. latitude.



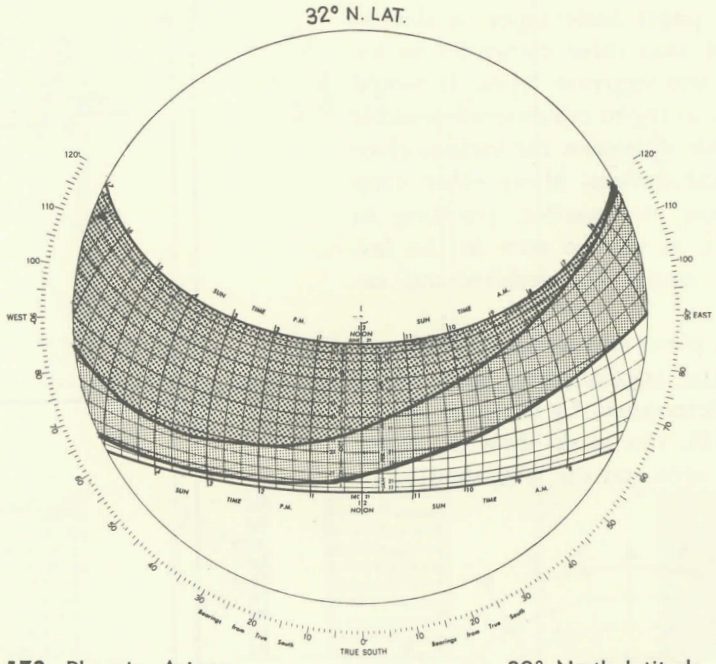
170. Miami, Florida, 24° N. latitude.



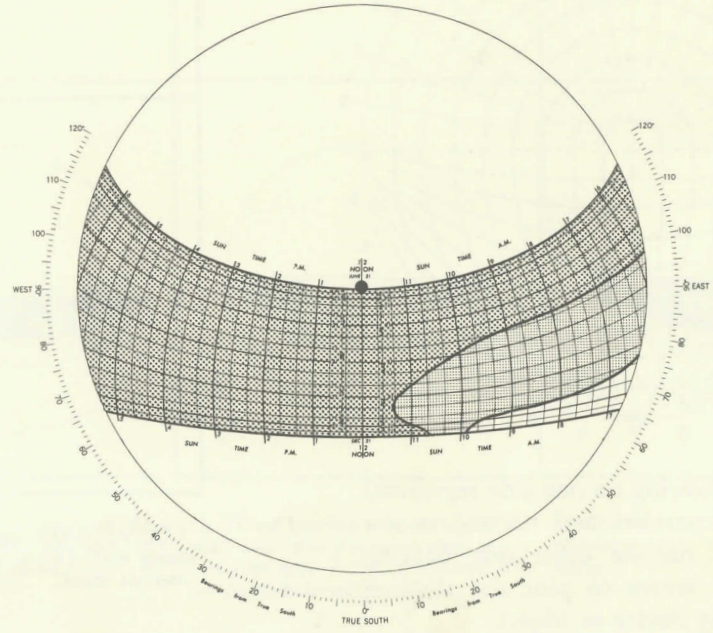
171. Minneapolis, Minnesota, 44° North latitude.



172. New York-New Jersey area, 40° North latitude.



173. Phoenix, Arizona, 32° North latitude.

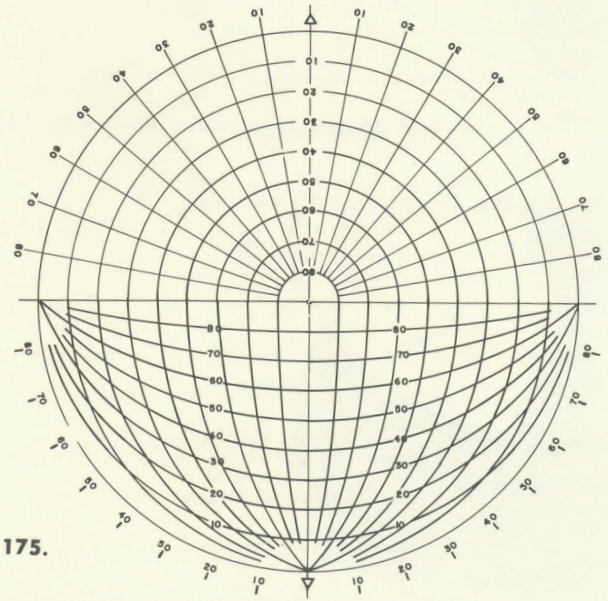


174. Miami, Florida, 24° North latitude.

VOCABULARY OF SHADING DEVICES

ON the following pages basic types of devices are shown divided into three categories as horizontal, vertical, and eggcrate types. It would be an infinite task to try to tabulate all possible forms, but this table illustrates the various characteristics of typical devices. Many other combinations of devices are possible, resulting in combinative masks, as can be seen in the last part of this book among the architectural examples.

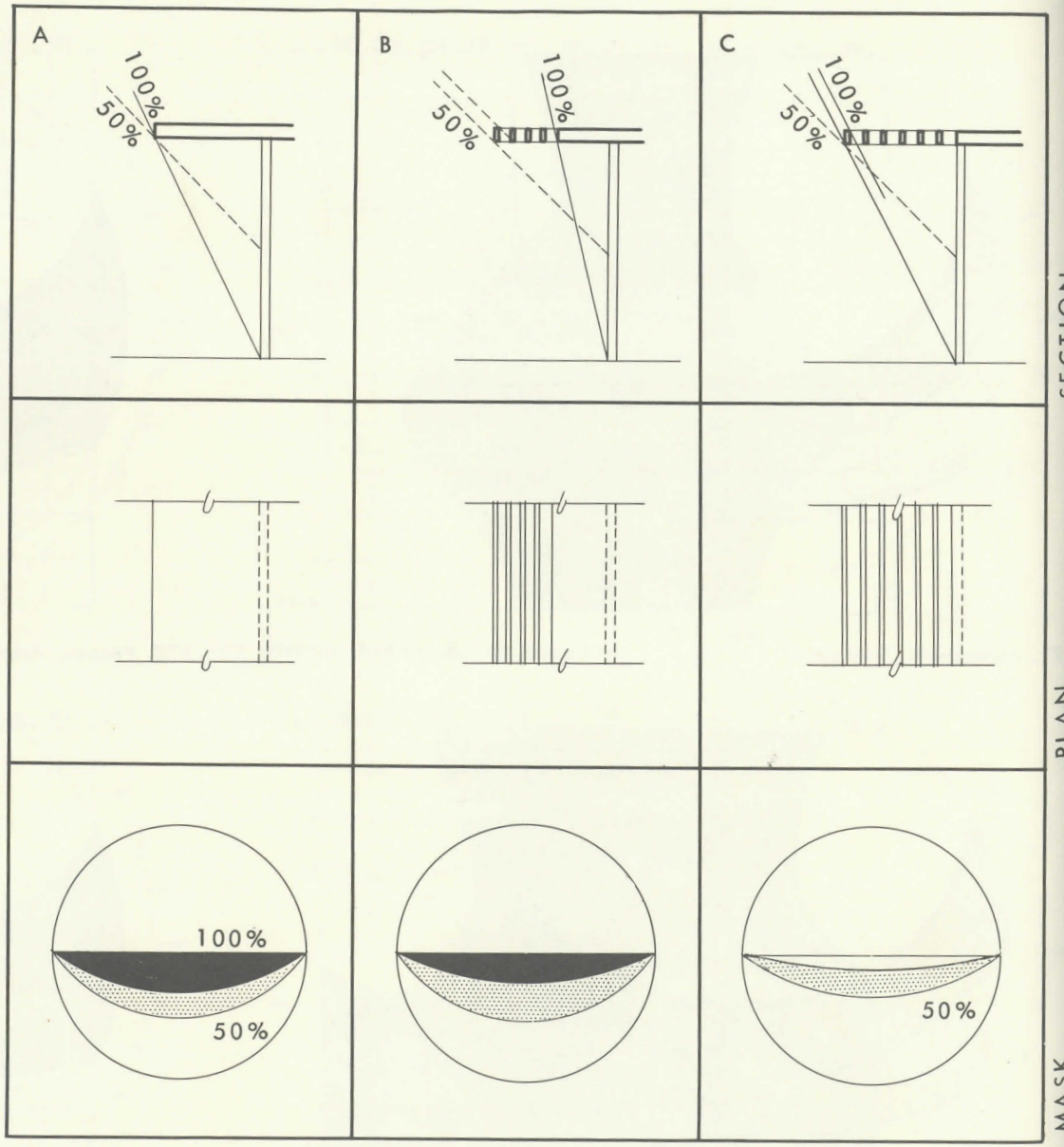
Here elevations, plans and sections are shown with their schematic angular lines with which the mask can be determined by the used of the protractor (Fig. 175). The masks show the 100% shading as a black area and the 50% shading in gray.



175.

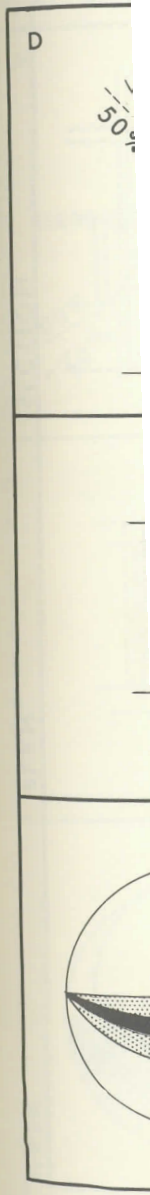
The protractor showing on one side segmental lines to plot lines parallel and normal to the observed wall and on the other side bearing and altitude lines, serves to plot the shading mask of any shading device or object.

HORIZONTAL TYPES

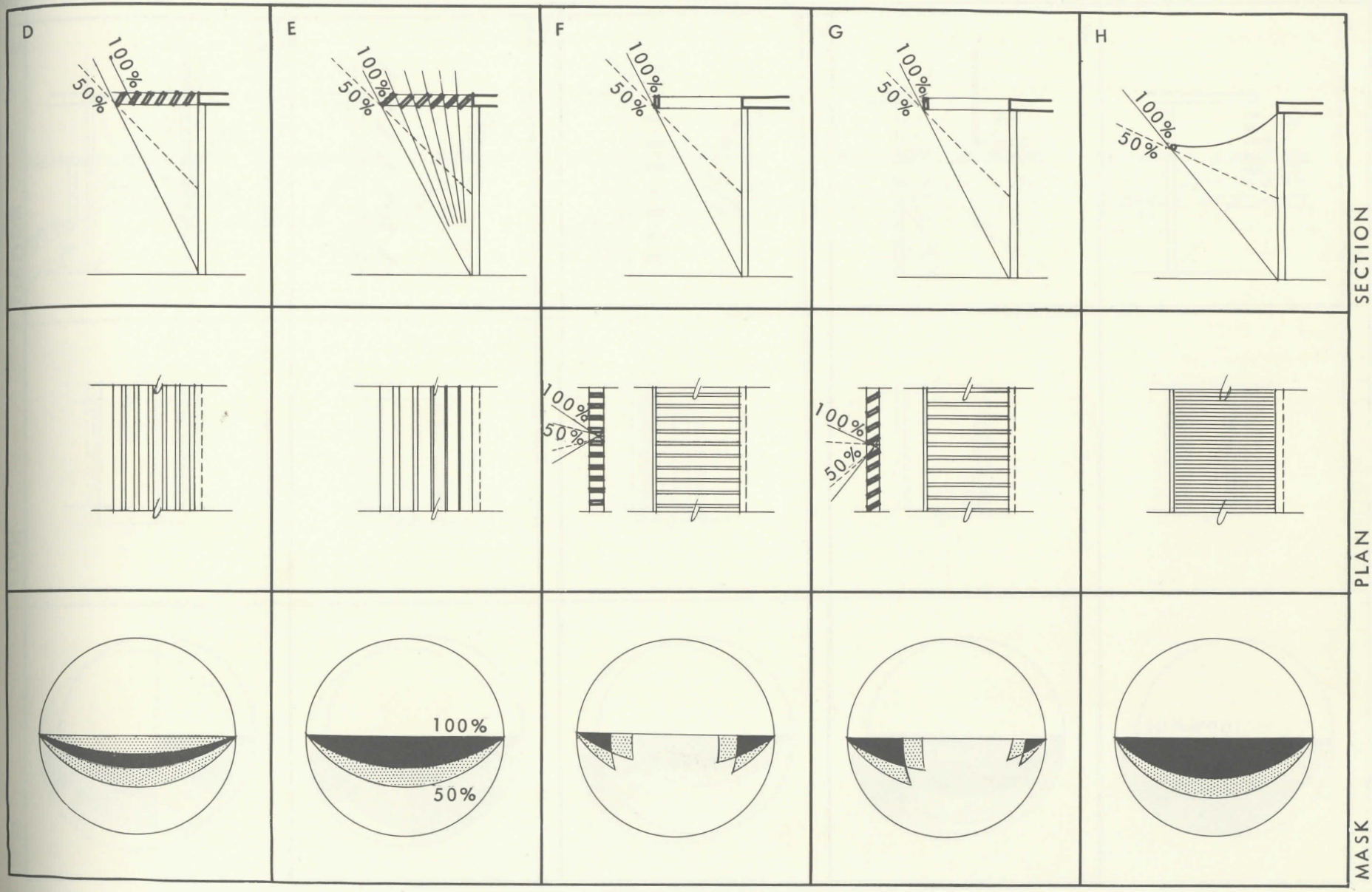


176. A. Solid horizontal overhang with 100% and 50% segmental mask. B. Overhang partially solid, partially louvered. C. Louvers parallel to wall, which do not secure 100% shade, therefore the mask shows only 50% shading.

HORIZO



177. D. Ti
wall let in
altitudes, a



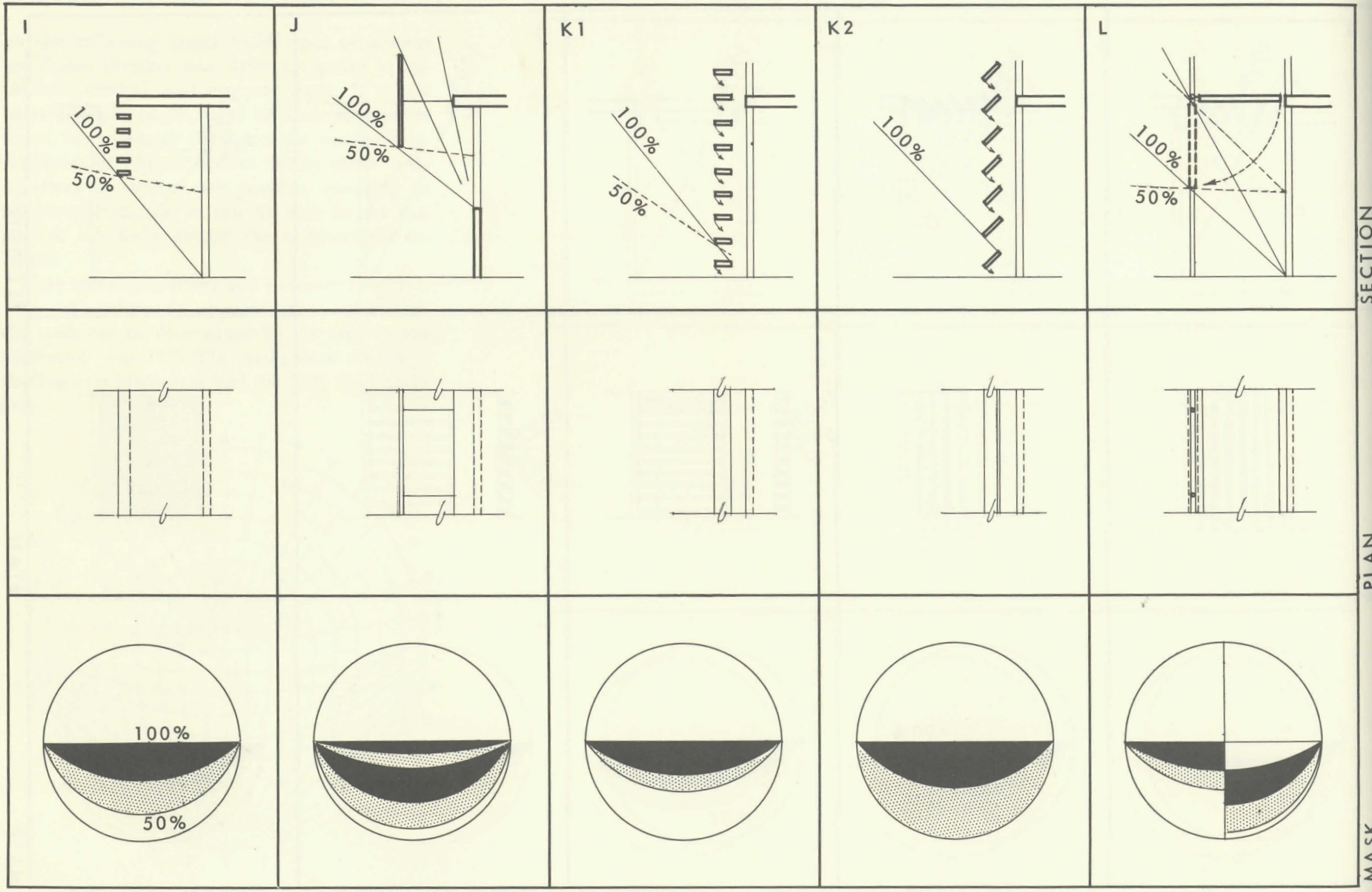
177. D. Tilted louvers parallel to wall let in some sunrays at high altitudes, as shown in mask.

E. Tilted louvers parallel to wall, but unequally spaced will secure 100% shading at high sun altitudes also.

F. Overhangs with louvers perpendicular to wall will cut out sunrays from the sides.

G. Tilted louvers perpendicular to wall will have the same characteristics as type F, but the mask will be asymmetrical.

H. Canvas canopy will have same characteristics as a solid overhang.



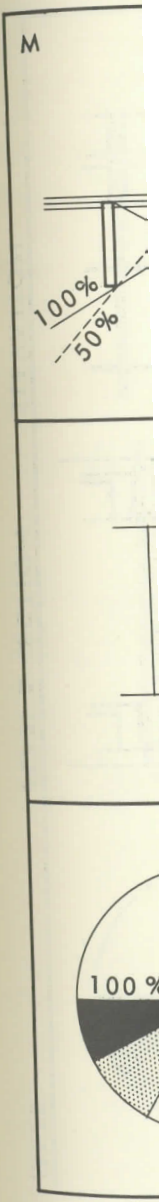
178. I. Horizontal louvers hanging from solid overhang might result in a large segmental mask.

J. A solid strip parallel to wall cuts out the lower rays of the sun. If the strip is made of heat-repellent glass, it will not secure 100% shading.

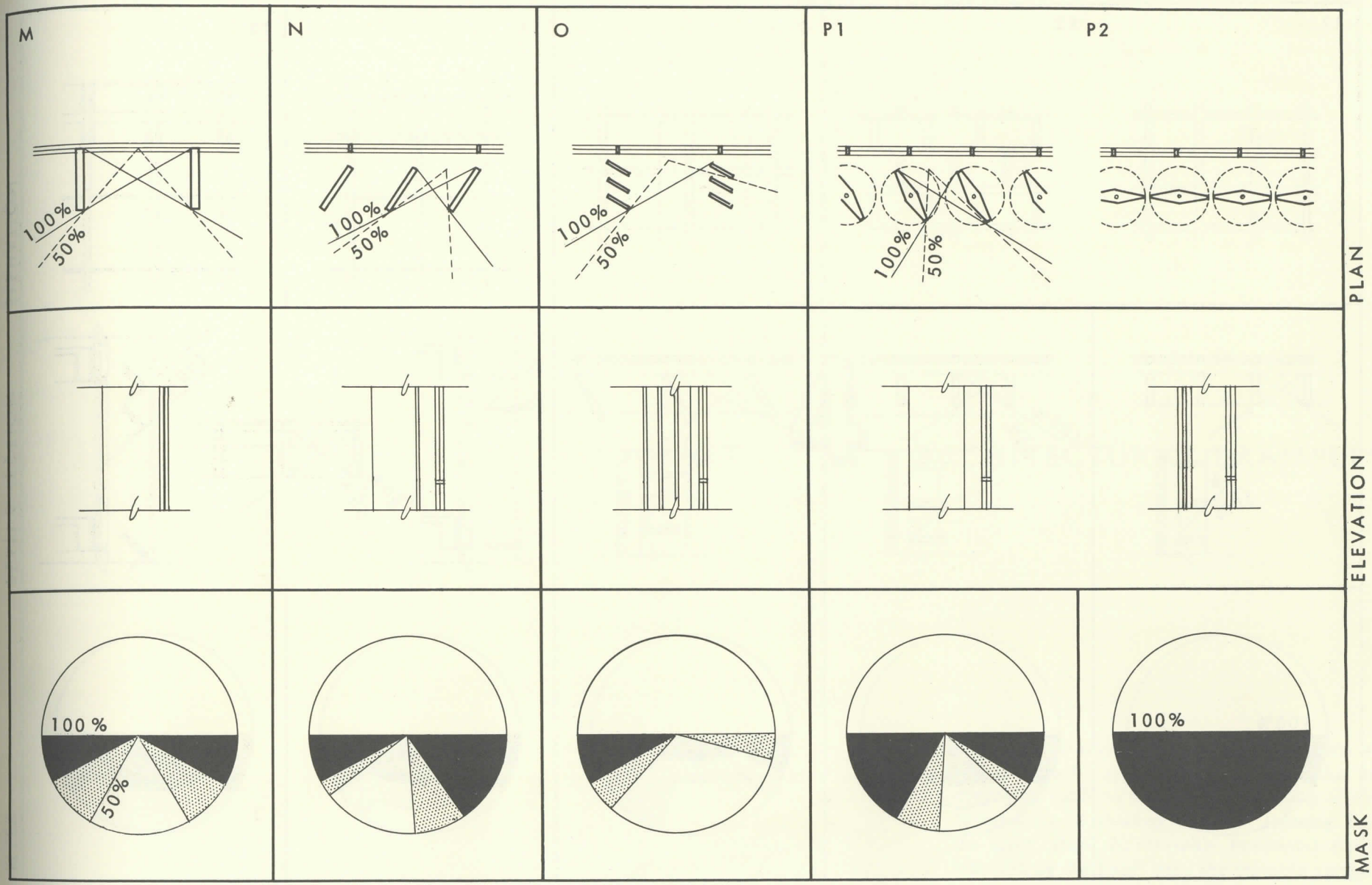
K1. Movable horizontal louvers change their mask characteristics according to their positioning.

K2. The same device as shown before in horizontal positioning is tilted in 45° angle.

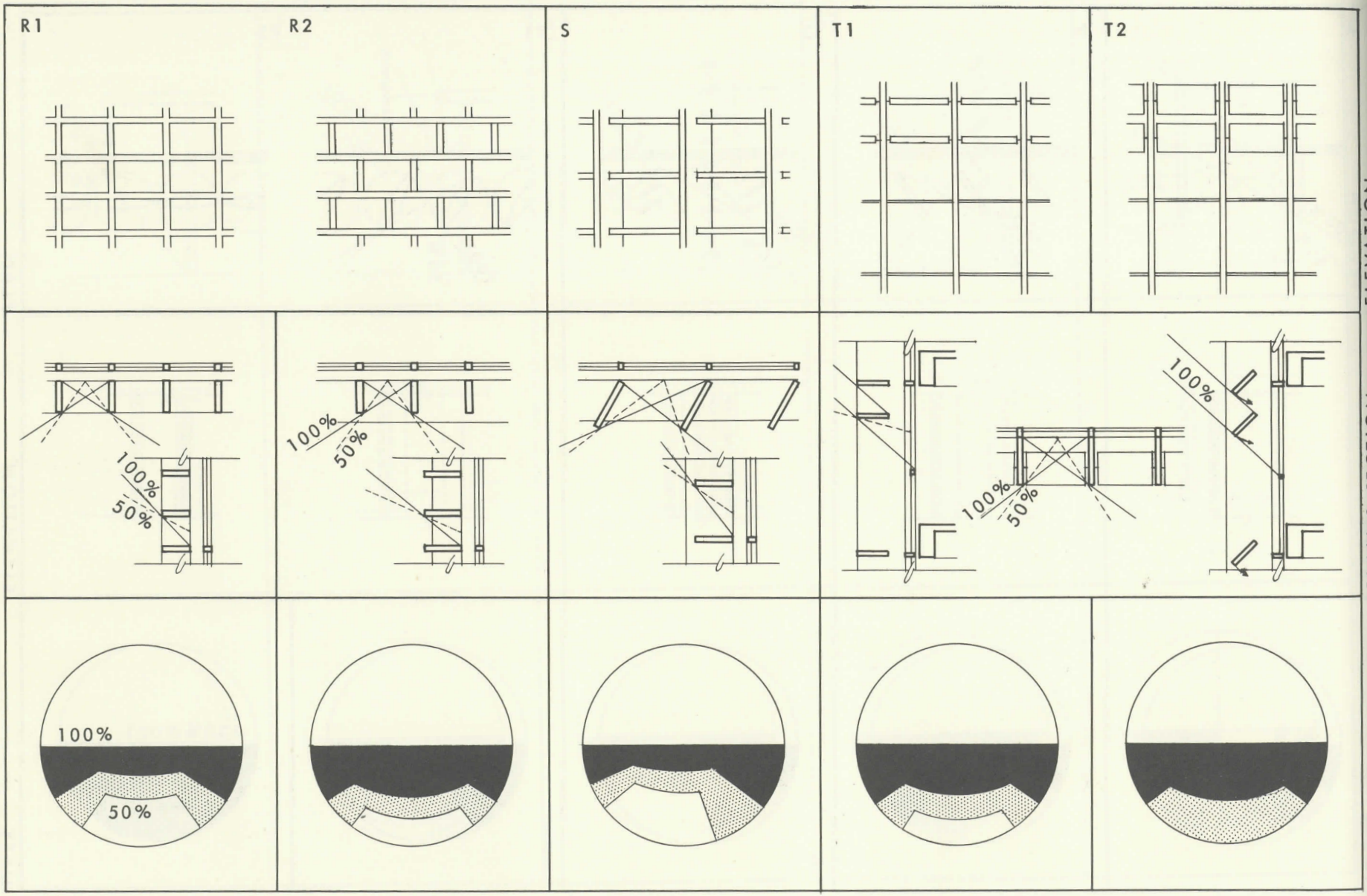
L. Movable horizontal device (as in example on pages 122-123) will have different mask characteristics.



179. M.
100% ar



179. M. Solid vertical fin with 100% and 50% radial mask. N. Vertical fin oblique to wall will result in an asymmetrical mask. O. With vertically louvered fins masks can be designed which give 100% shading only to one side. P. Movable vertical fins can shade the whole wall, or open up in varied directions, but their mask will always have radial characteristics.

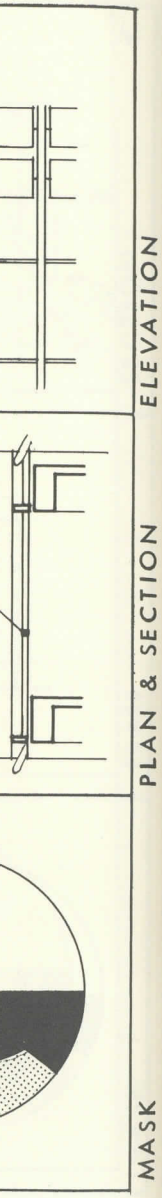


180. Eggcrate types are combinations of horizontal and vertical types and therefore their mask is a superimposed diagram of the two masks. As type "A," a solid horizontal overhang combined with type "M," a solid vertical type gives type "R." R_1 and R_2 could have the same mask, depending on their horizontal and vertical measurements.

S. Solid eggcrate with slanting vertical fins results in an asymmetrical mask.

T1. Eggcrate device with movable horizontal elements change their mask characteristics according to their positioning.

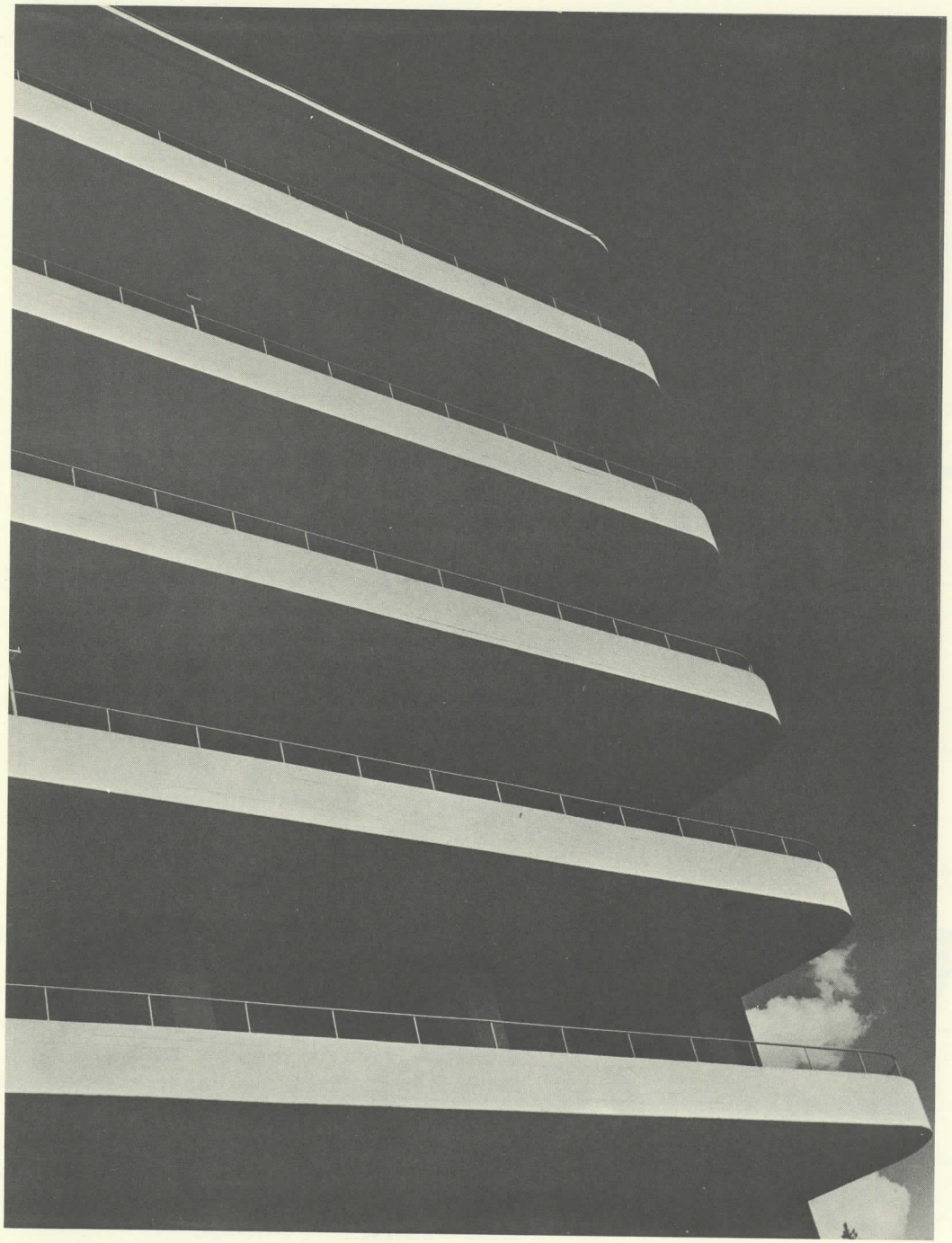
T2. The same device, shown before in horizontal position, is tilted in 45° angle.

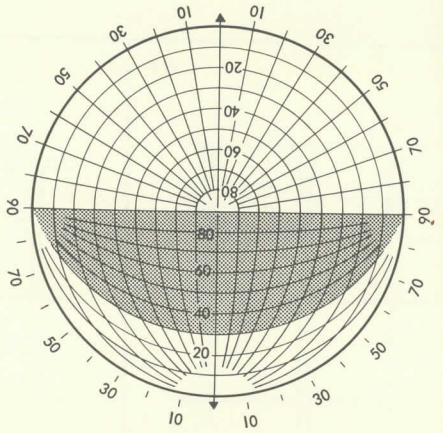


, shown be-
position, is

PART 4 ARCHITECTURAL EXAMPLES

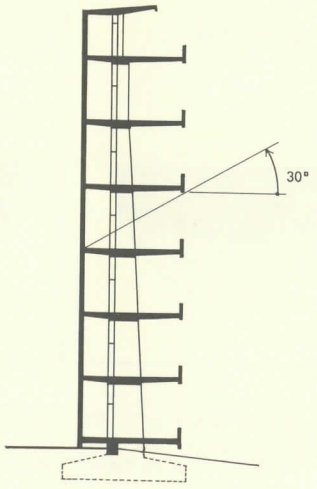
This part illustrates the visual expressions of sun-breakers by architectural examples. An attempt was made to order them according to the "vocabulary of shading devices," showing first the fixed, then the movable horizontal types, followed by the fixed, then the movable vertical ones, and later the fixed and the movable egg-crate types. Some special types follow at the end. Their technical characteristics are shown with their shading masks, with the 100% and sometimes with the 50% coverage.



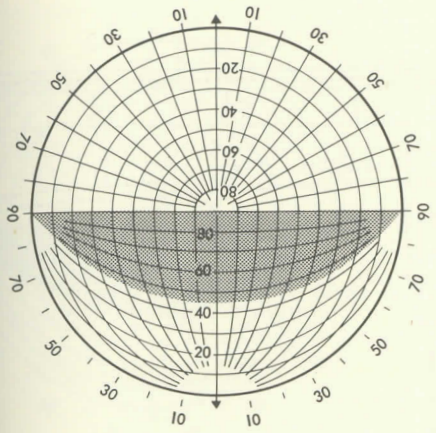


ALVAR AALTO, *Sanatorium for Tubercular Patients, Paimio, Finland*

A series of superimposed terraces provide pleasing solar decks for tubercular patients. The structure consists of reinforced concrete cantilever slabs supported by six tapering piers. The cantilever floors are closed toward the north, and are open to the south, thus admitting solar rays. The sweeping horizontal floor bands provide a striking architectural character to the structure.

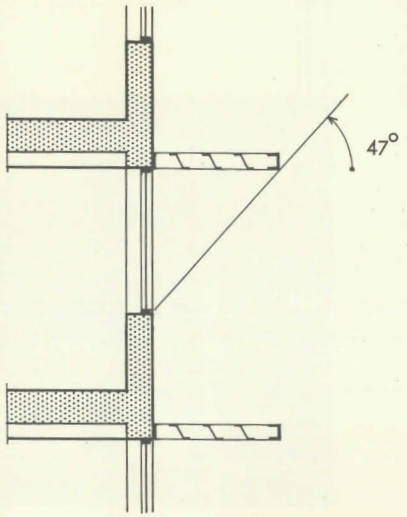


SECTION

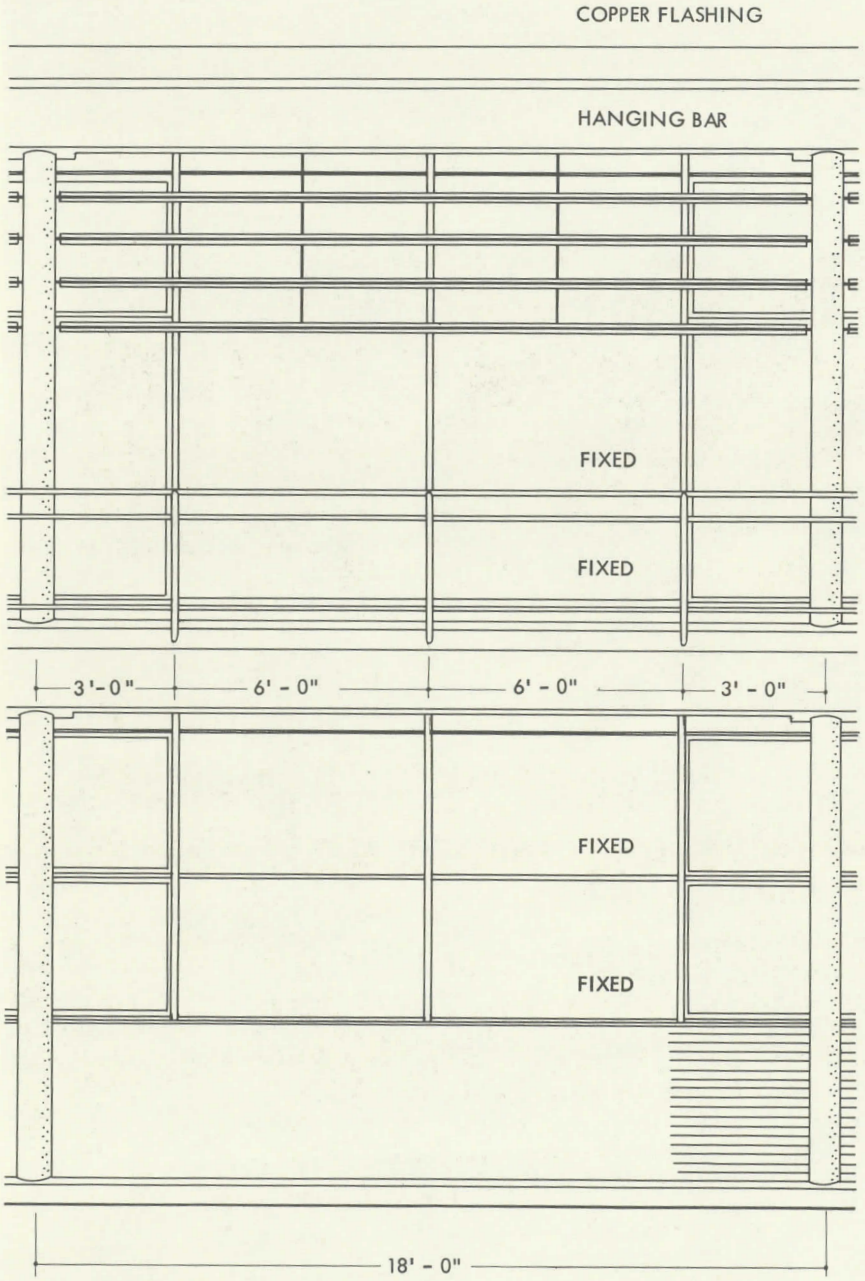


WURDEMAN & BECKET, *Prudential Building, Los Angeles, California*

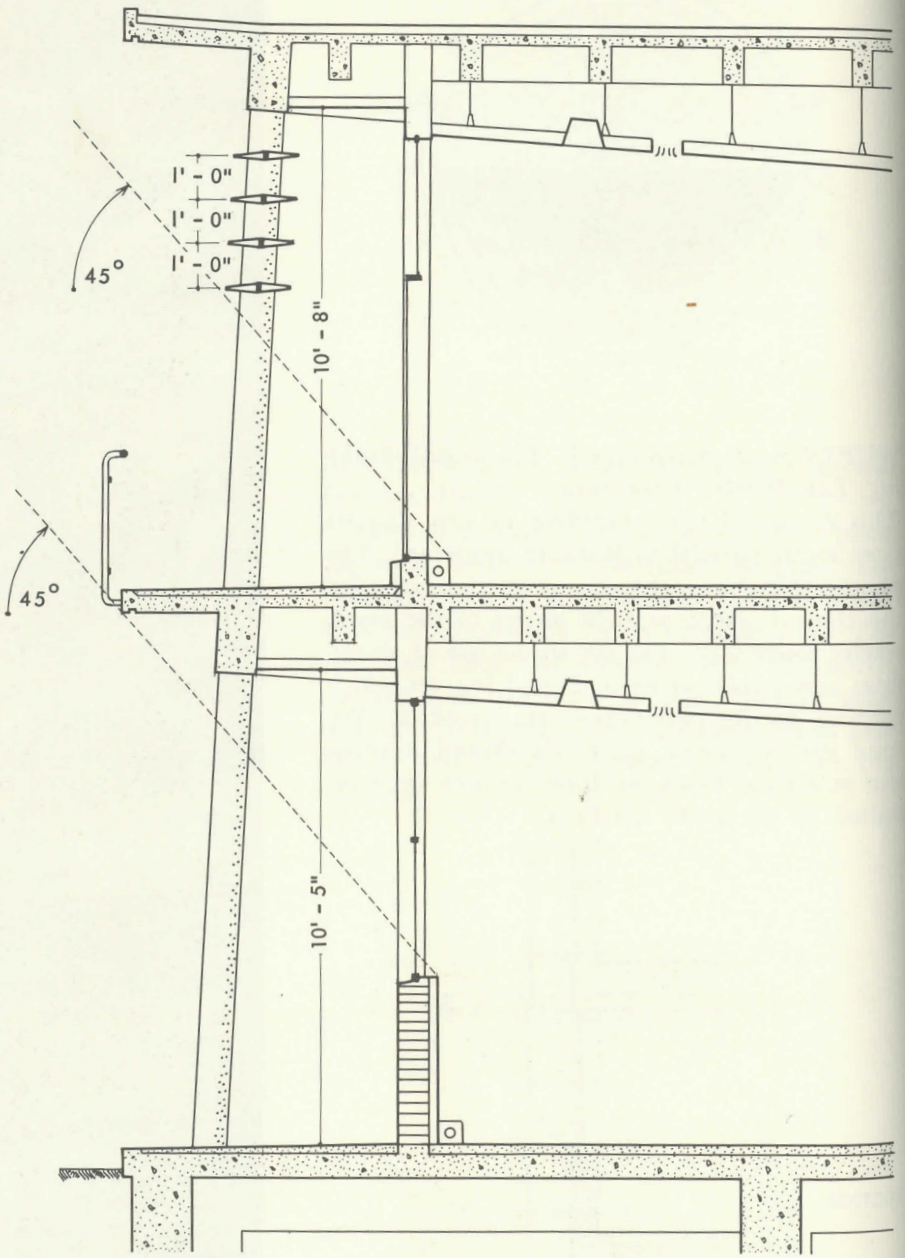
This elongated office building in Los Angeles faces south, parallel to Wilshire Boulevard. The photograph shows the sun protection afforded the clerical offices, at right angles to the blank service tower wall. The sun-shades are of aluminum and consist of fixed slanted louvers which contrast to the pink terra-cotta spandrels. Despite the sunshades, glare has proved a problem at certain times, so draw curtains were installed on the south windows.



SECTION



ELEVATION



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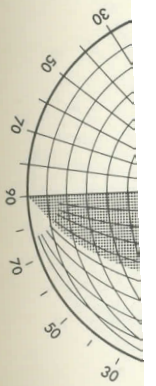

RAYMOND & R
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The office buildir
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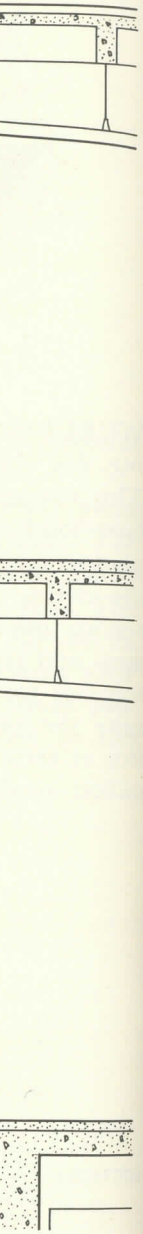
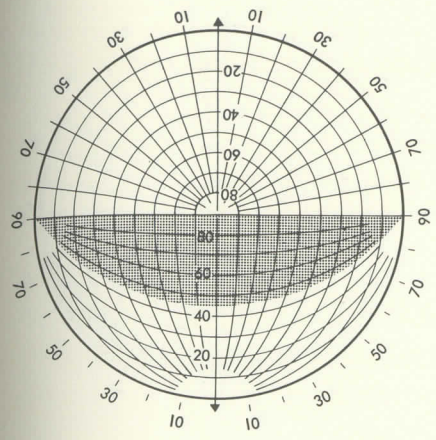
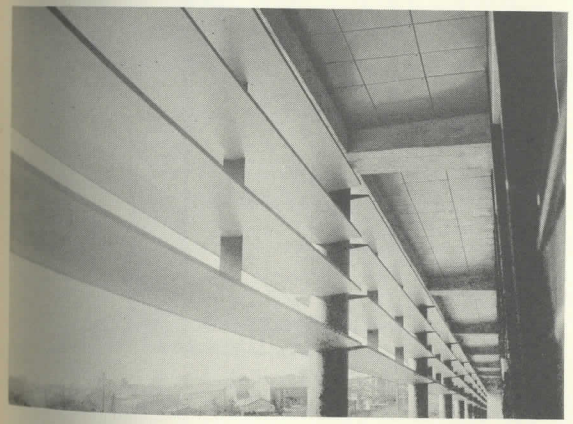
and steel.

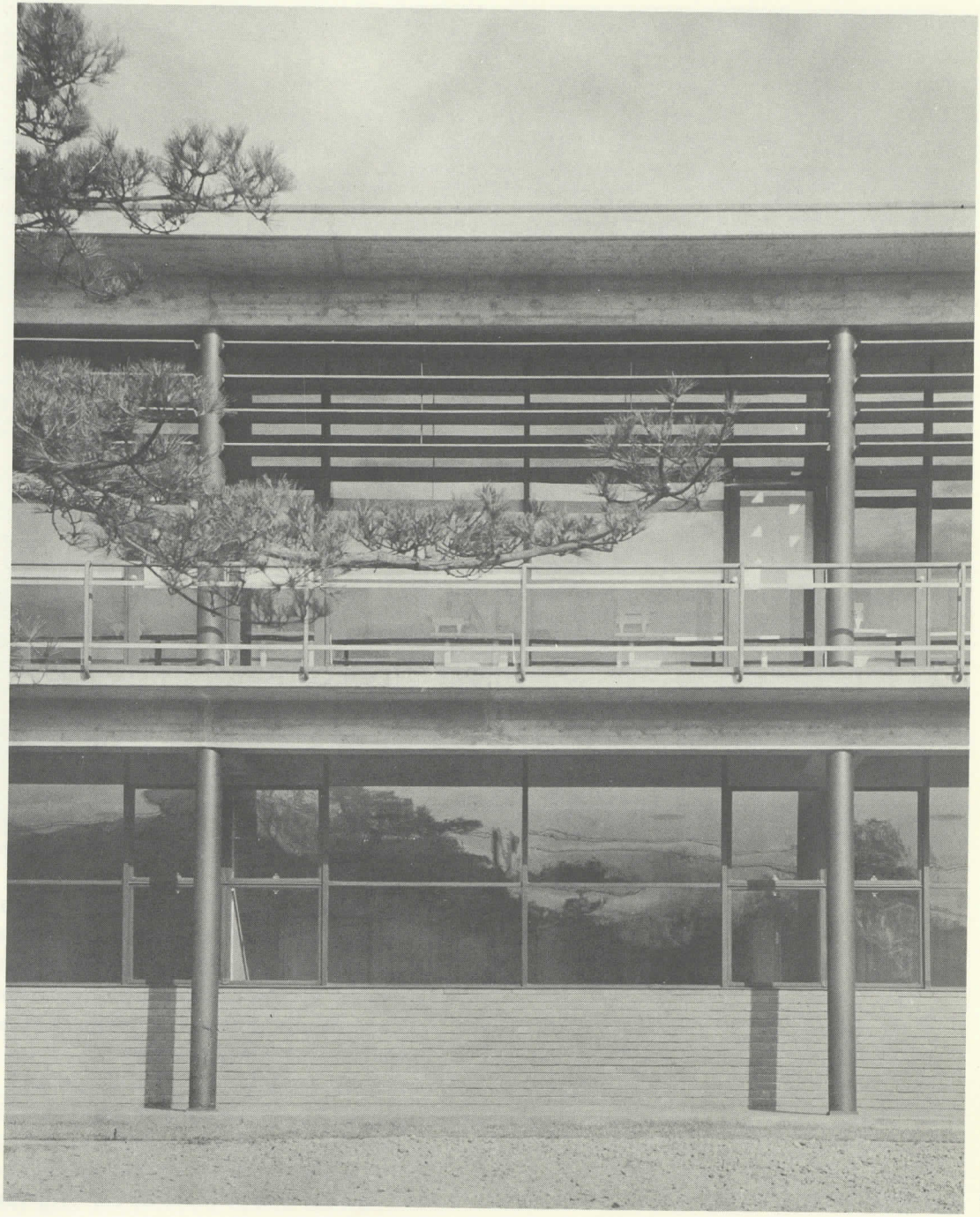


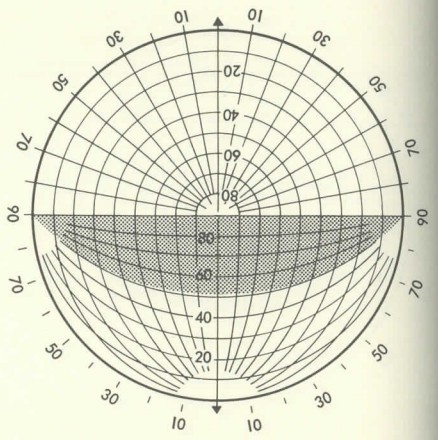


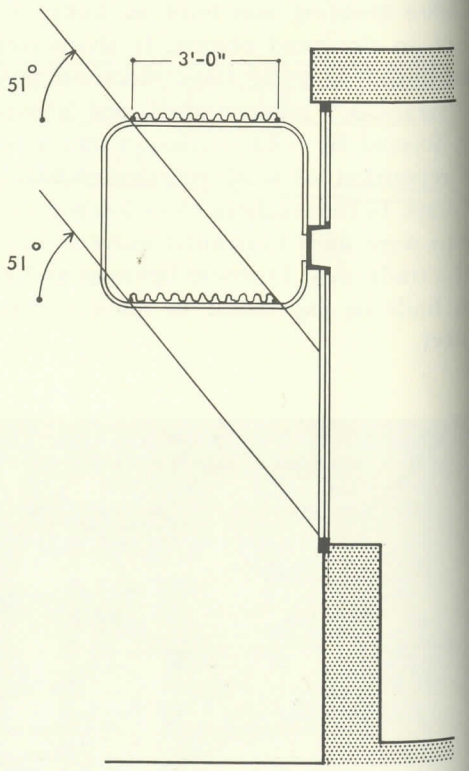
RAYMOND & RADO, *Reader's Digest Building, Tokyo, Japan*

The office building was built in Tokyo in the form of an elongated oblong. In sharp contrast to the boxed end, the front elevation presents two "verandas," superimposed one above the other, formed by bold overhangs and accented by a repetition of steel columns marking off 18'-0" bays. In the southern elevation between the columns were fixed horizontal louvers. Thus resulted a traditional Japanese lightness and grace, which finds its expression in modern concrete and steel.



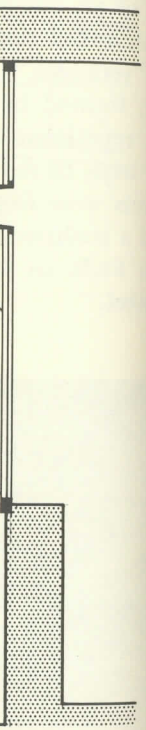




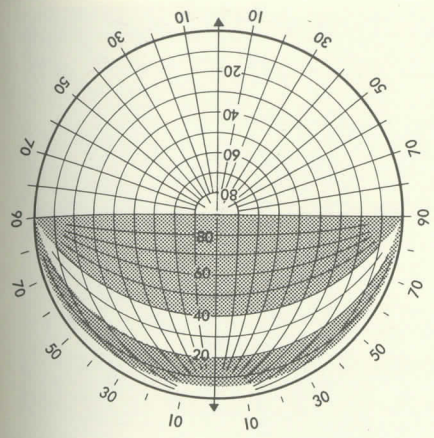


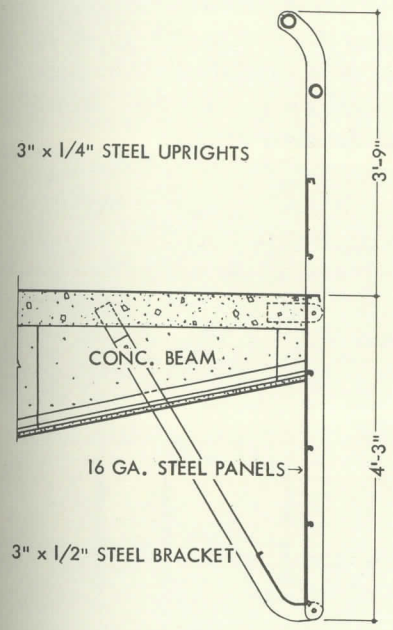
SECTION

COCKE, BOWMAN, YORK, *Rio Grande School, Rio Grande, Texas*
A double horizontal overhang is constructed of metal pipe brackets with continuous corrugated aluminum sheets. This device gives a good protection against solar heat on the south walls. The space between the aluminum panel and the wall secures air circulation.



SECTION

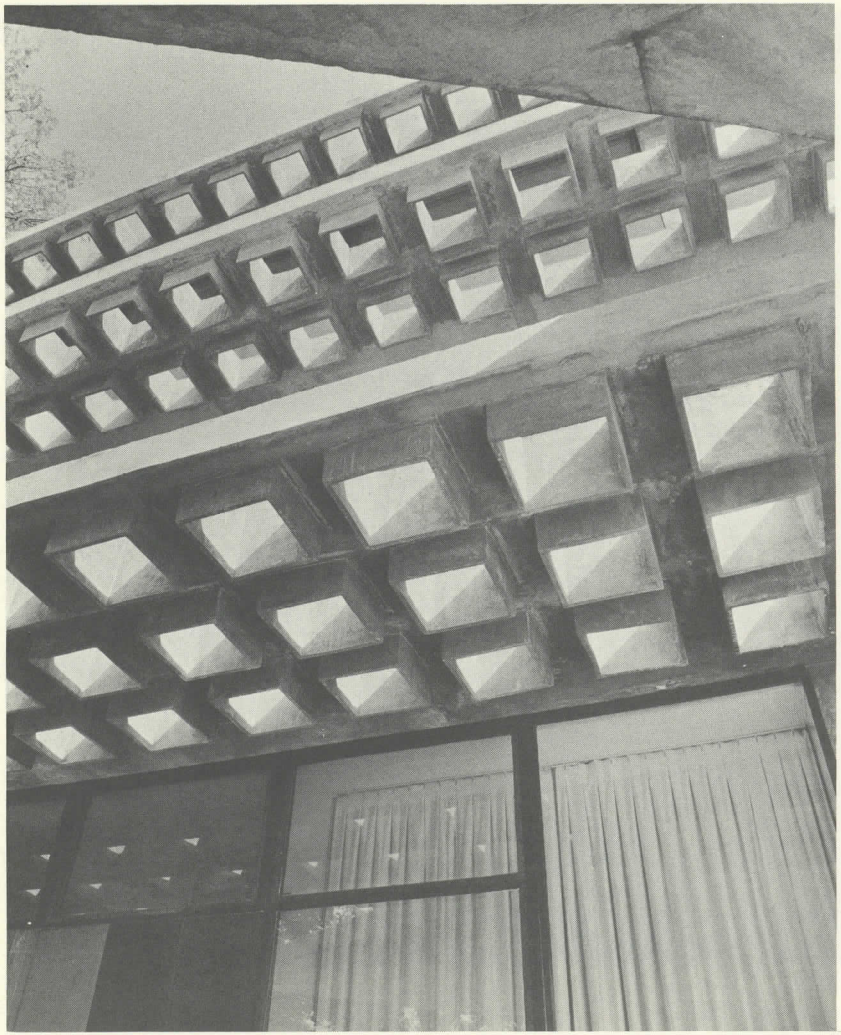


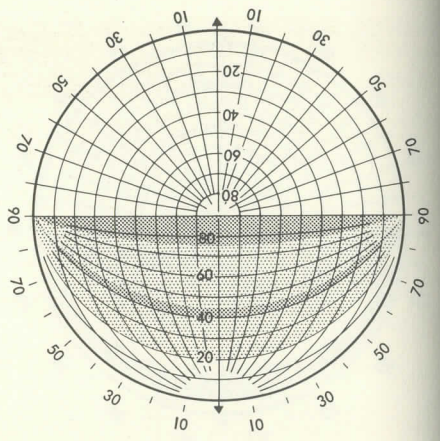


SECTION THRU GALLERY RAILING
AND SUN SHADE

ROBERT LAW WEED, *University of Miami, Miami, Florida*

The detail shows a combination of balcony and railings used for sun control. Here, in order to obtain complete sun control, the overhang, or balcony, would have to project so far out that it would become difficult to build. An interesting detail was created whereby the railing-support extends down below the balcony and supports steel panels, which in combination with the balcony give the solution of sun control.

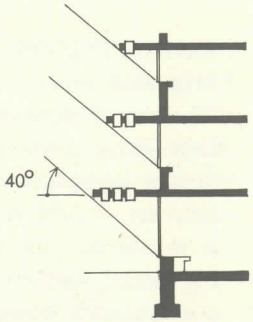




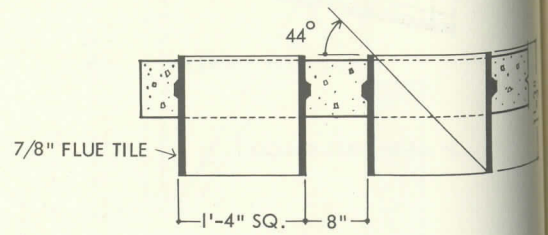
LOUIS I. KAHN, *Samuel Radhill Building, Philadelphia Psychiatric Hospital, Philadelphia, Pennsylvania*

The decorative perforated overhang shows an interesting principle with its varied projection on different floors. On the upper floors where the glass surface is small it projects less and grows toward the ground floor according to the height of the glass surface.

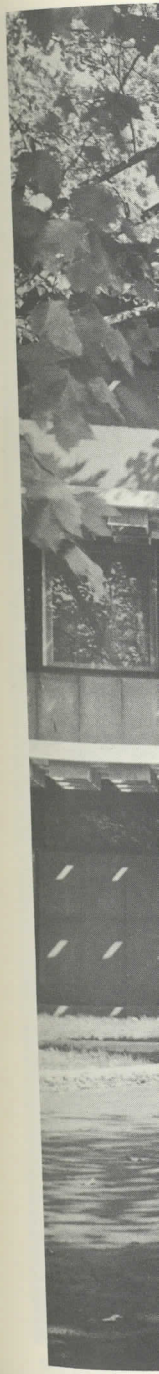
The overhang is built with the use of ordinary flue tiles, with a special collar to grip the poured concrete frame. The open tiles let light through as well as making fascinating sun patterns that shift from irregular, oblong, to squares, to triangles.

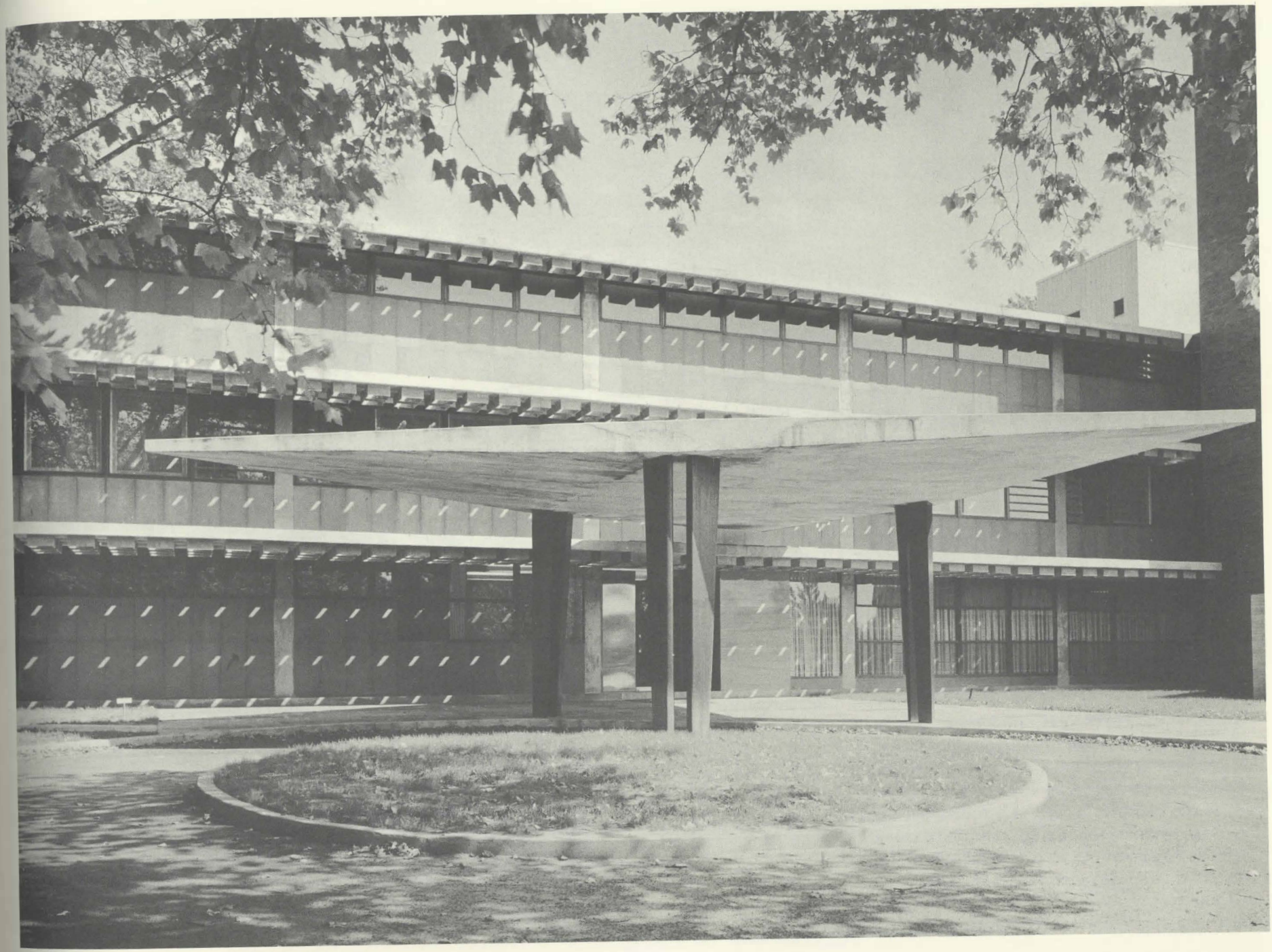


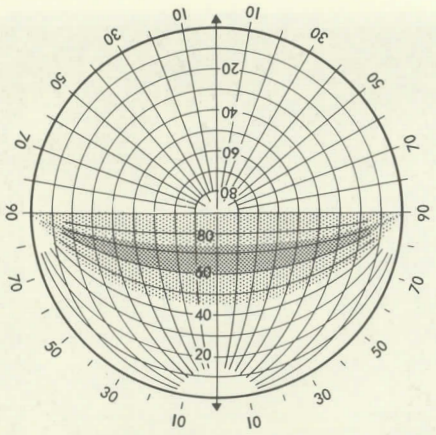
SECTION

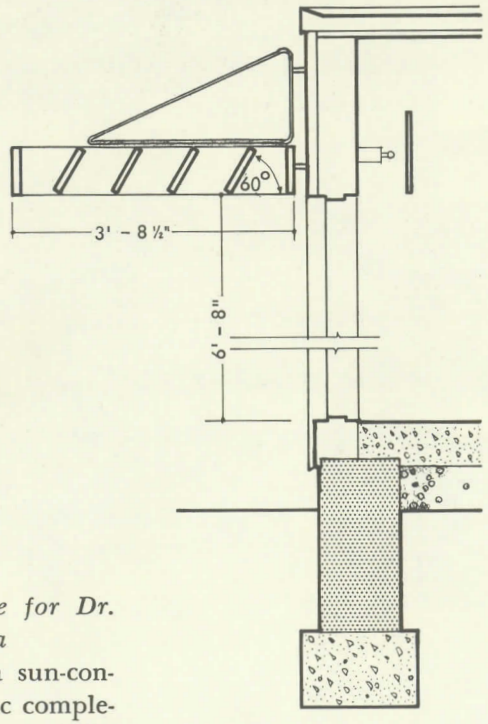


DETAIL OF OVERHANG









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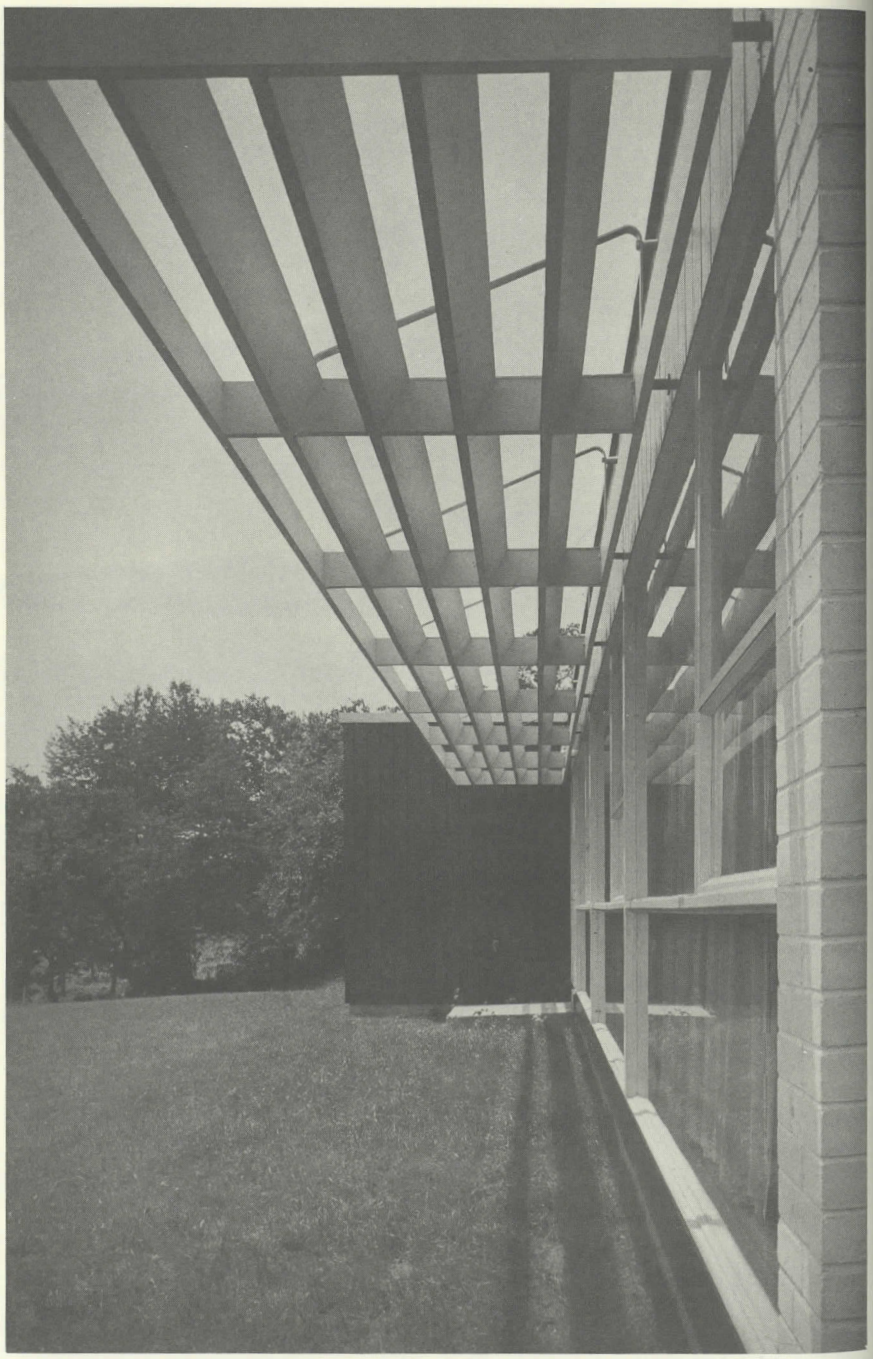
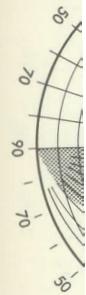


WILLIAM W. ESHBACH, *Residence for Dr. S. K. Rossman, Wyncote, Pennsylvania*
The continuous glass walls demand a sun-control device which would be an aesthetic complement to the building as well as a functional device. The overhanging louvers are fixed to a triangular bracket of 1" × ¼" metal strap, and anchored to the fascia of the roof. The fixed wood louvers are set at an angle of 60.° to prevent the sun-rays from striking the glass.



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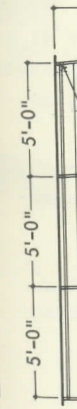

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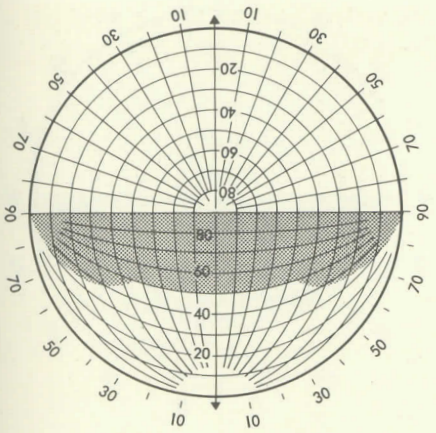
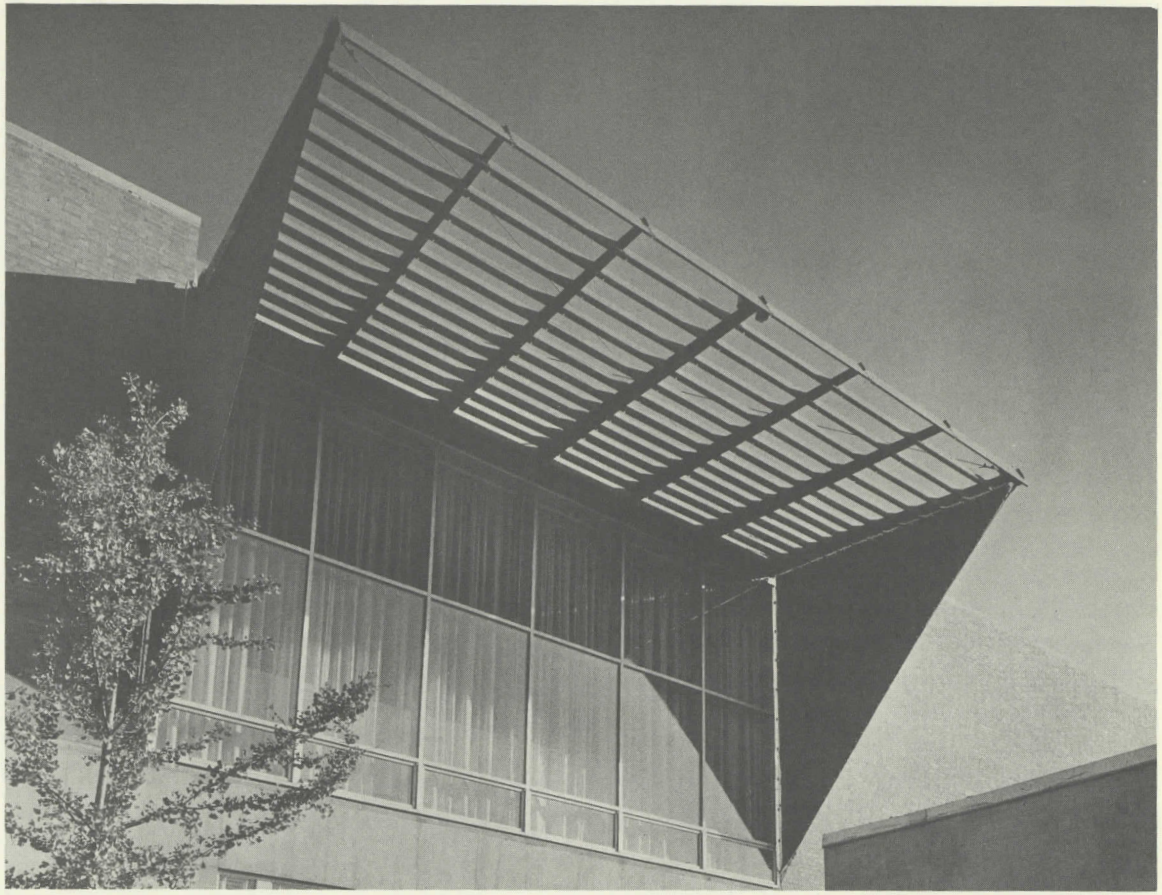
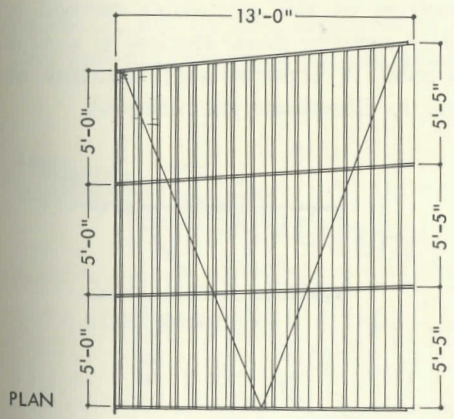
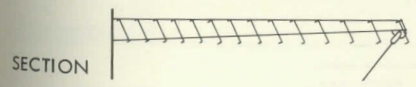


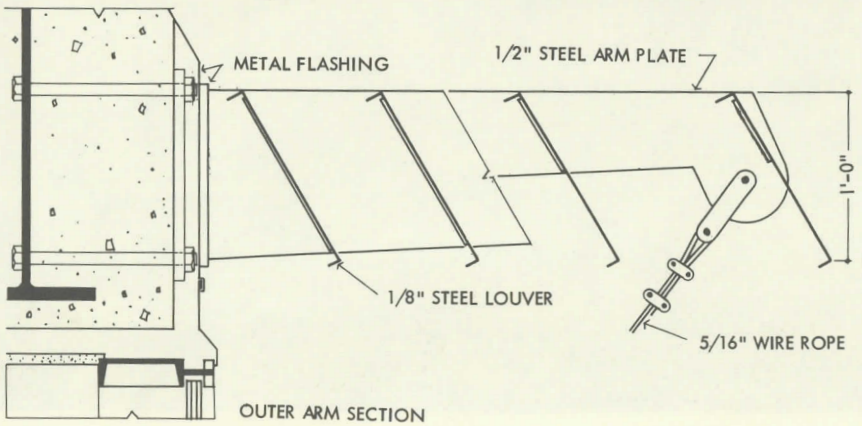
HARRIS ARMSTRONG, *Suburban Branch Department Store for Scruggs, Vandervoort, and Barney, Clayton, Missouri*

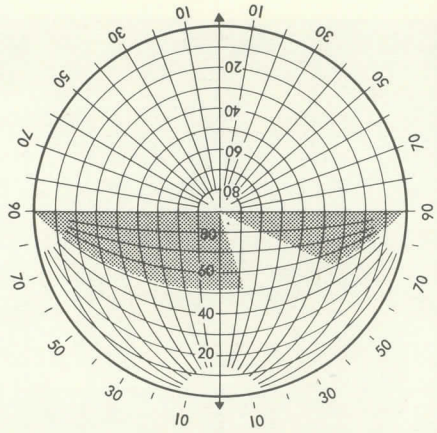
A louvered hood provides shade for a large second-story window. The upper projection is of fixed metal louvers, with the sides protected by triangles of canvas, anchored to the upper element and the masonry wall.





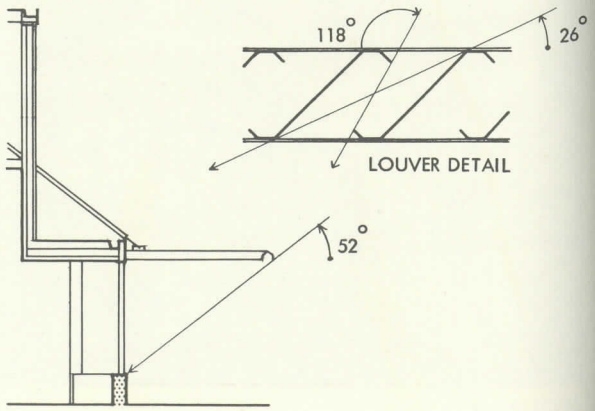


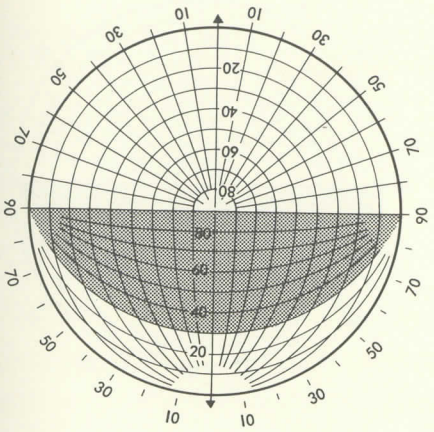




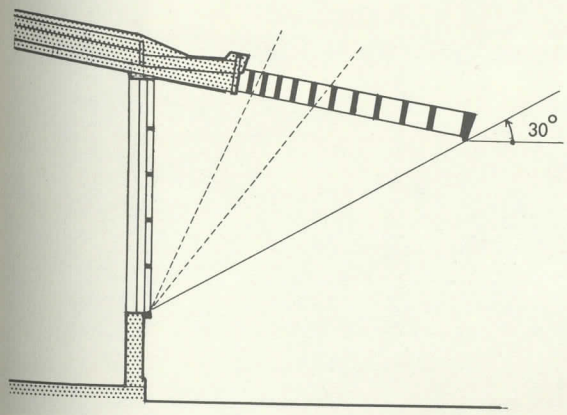
ROBERT E. ALEXANDER, *Baldwin Hills Shopping Center, Baldwin Hills, California*
This type of louver is actually a large fixed venetian blind, placed horizontally. The architect has used this to eliminate the conventional awning. The louvers are pitched in such a manner that morning sun can reach the window area for a short period, but for the remainder of the day no direct sunlight will enter the display windows.

The advantage of this particular method is that instead of creating dense shadow as a solid overhang would, it permits large amounts of diffused light to illuminate the windows.





HORN & MORTLAND, *Sunshine School for Cerebral Palsied, Fresno, California*
The continuous windows of the classroom wing are protected by a large louvered overhang. The device is constructed at the same angle as the roof; it is of wood and has fixed vertical slats. These slats are arranged progressively nearer to each other as they approach the roof. Thus a protection is given to the glass surfaces from the sun at any altitude. Basically it acts as a solid overhang, but by this arrangement air circulation and diffused radiation are gained.



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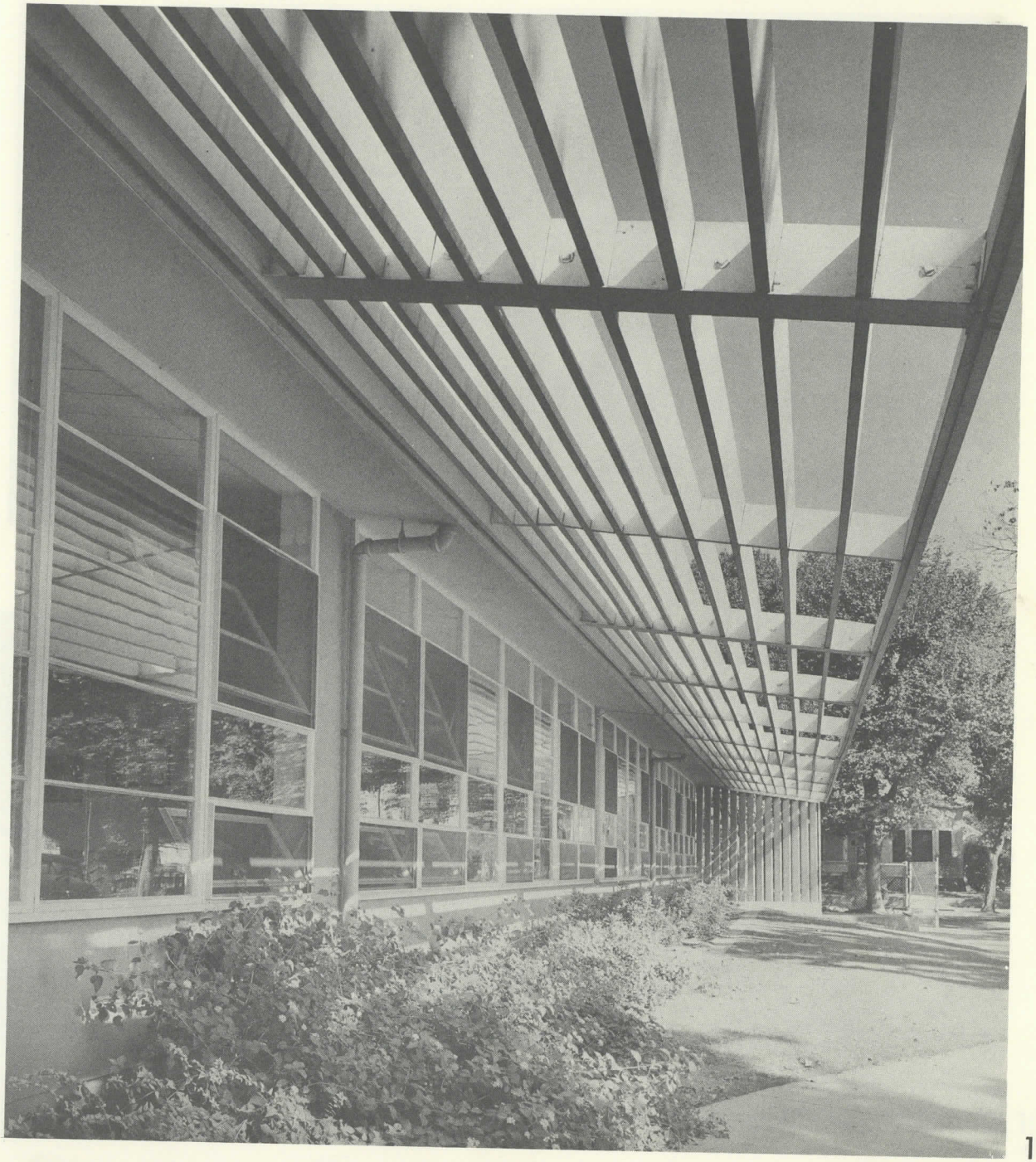
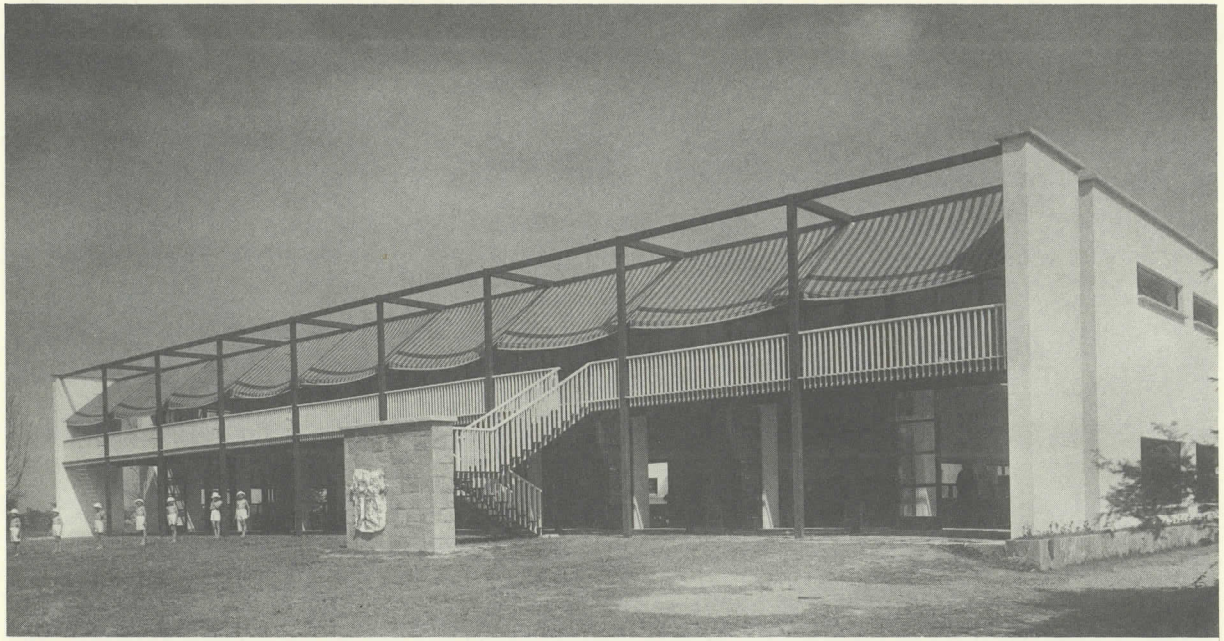
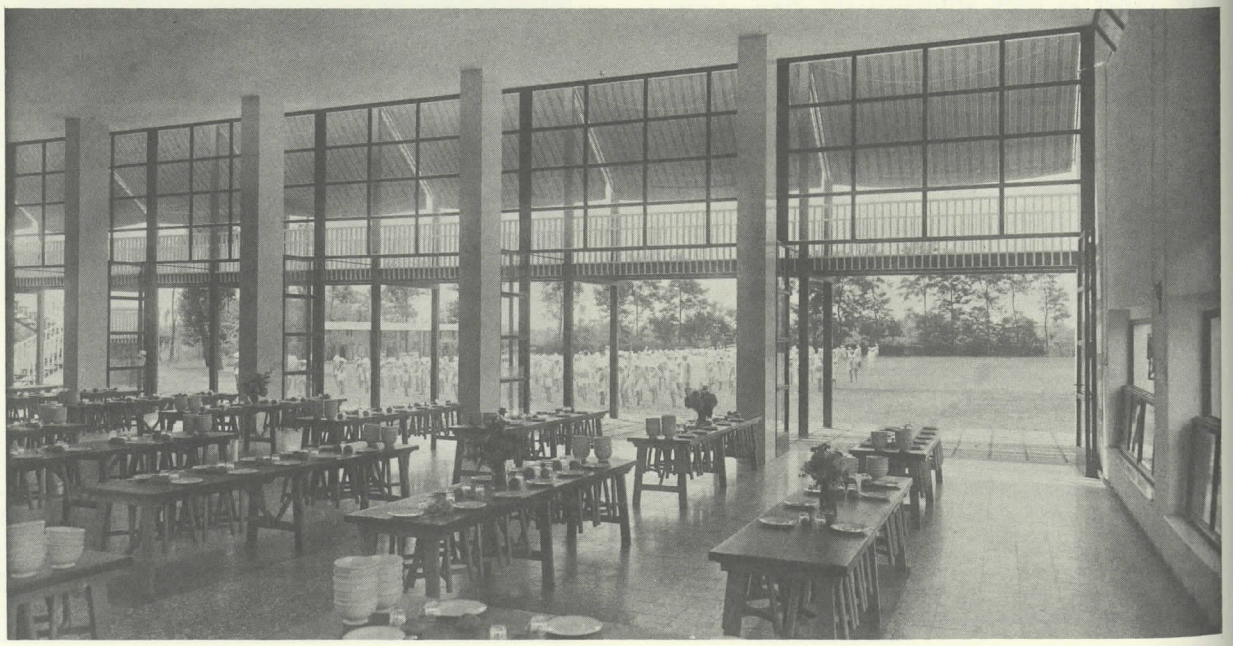




In contrast to the white stucco of the main building, this solarium construction is of dark wood members and gay blue and white canvas. The angular fixed canvas is supported by galvanized rods, in such a way as to be removed during the winter months.

BANFI, BELGIOIOSO, PERESSUTTI, ROGERS, *Sun Treatment Center, Legnano, Italy*
This health center for children is located on the north side of a hill near Legnano, Italy. The main block consists of locker storage, kitchen, and common rooms, all of which open to the south. This south wall is entirely glazed and can be opened in its entire length. Directly in front of it there is a two-story sun deck which acts as a sun-shade. Detached from the building, this element is a separate entity.



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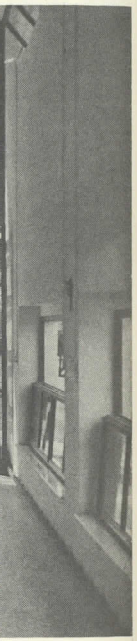

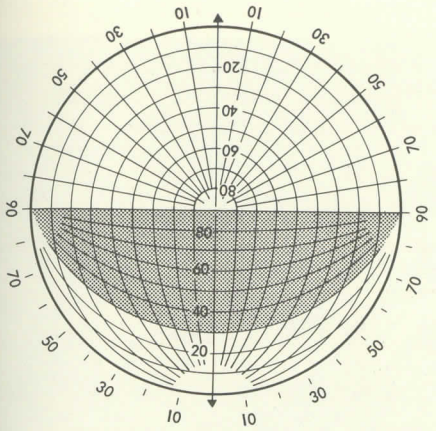

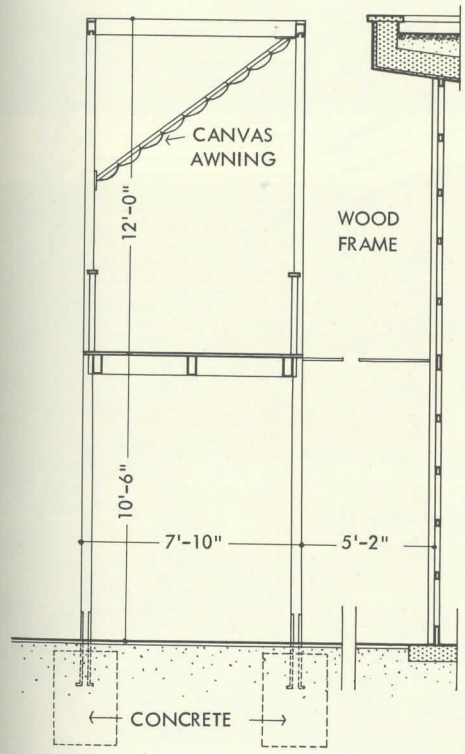

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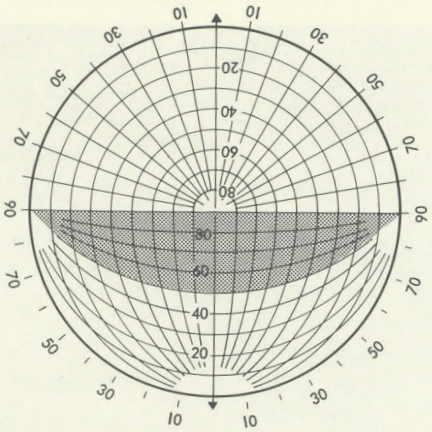
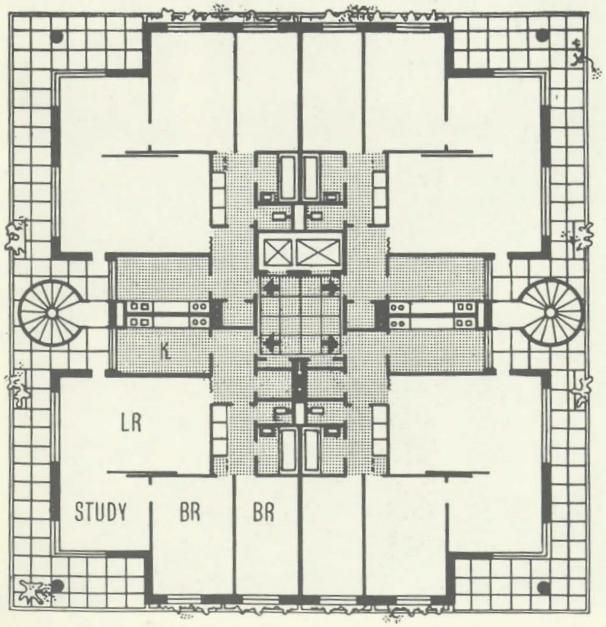
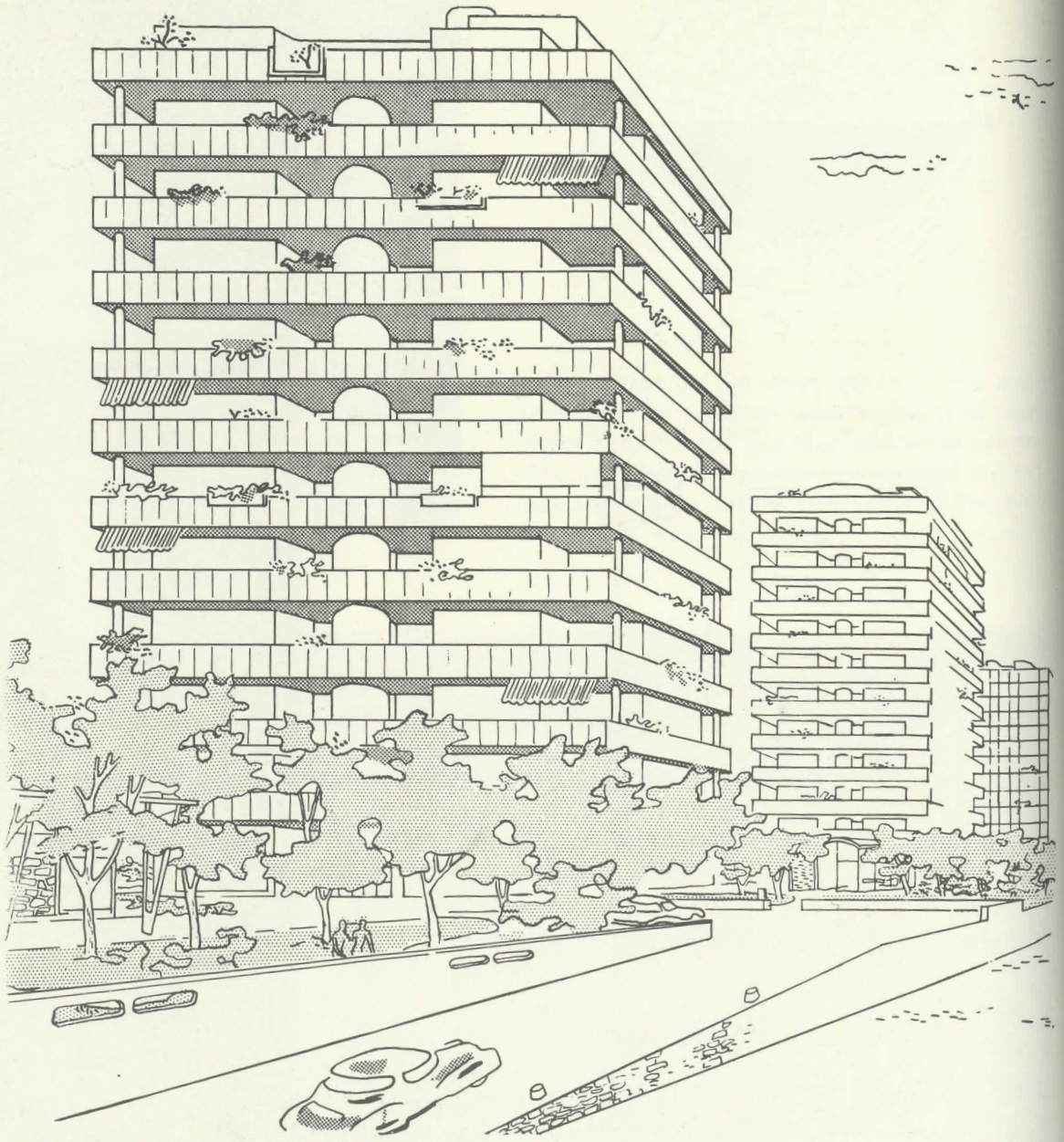
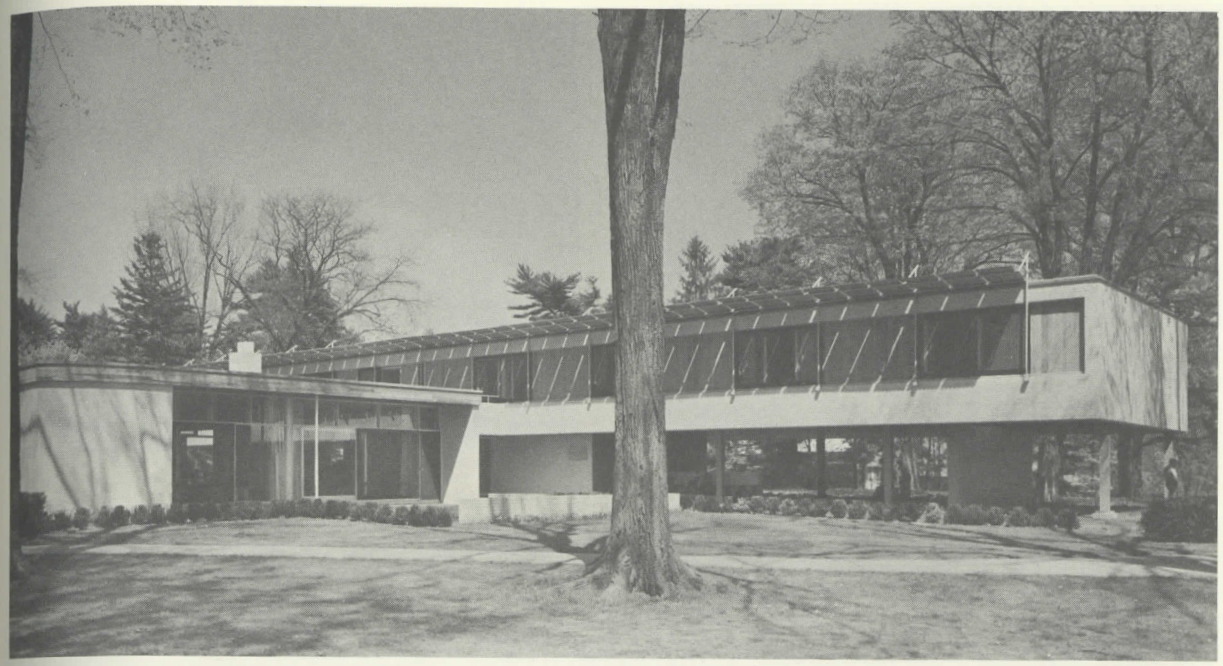


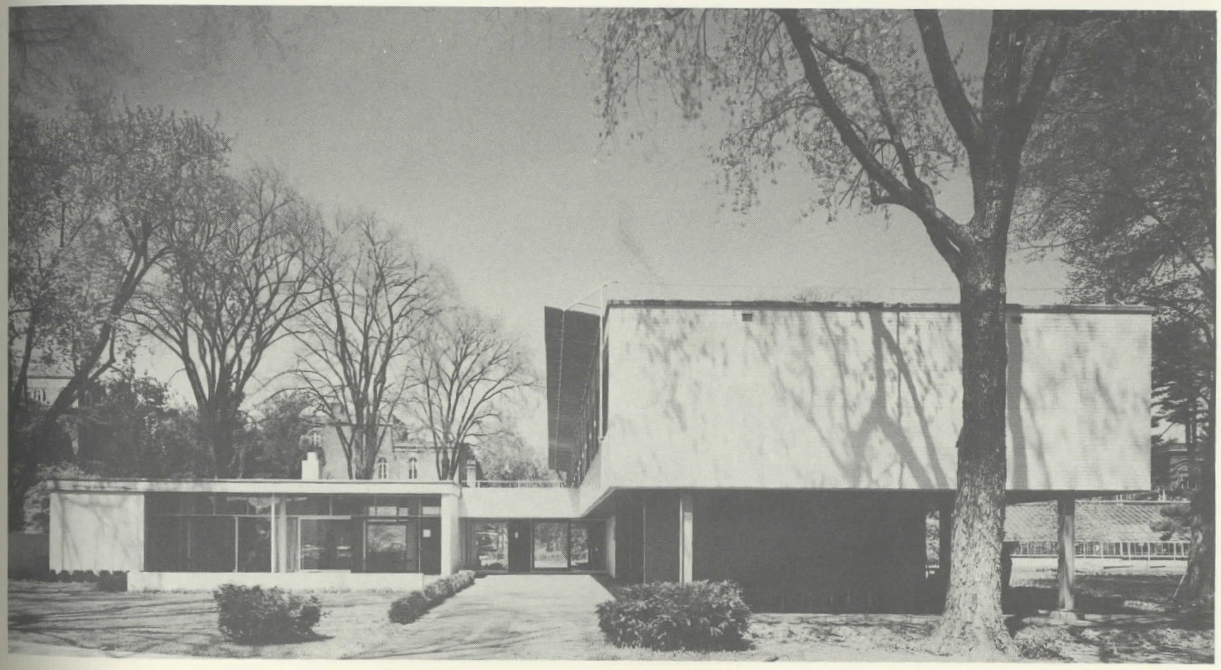
OLGYAY AND OLGYAY, *Tower Apartment Houses, Budapest, Hungary*

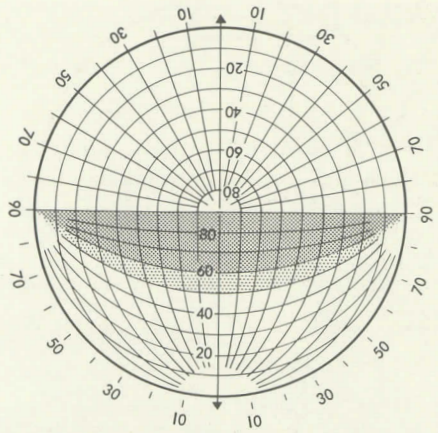
The character of this twelve-story apartment building is defined by the horizontal balconies which act as shading devices. The building itself is drawn back from the perimeter of the slab, in different depths according to the varied orientations. Each floor contains four apartments arranged around a central core.





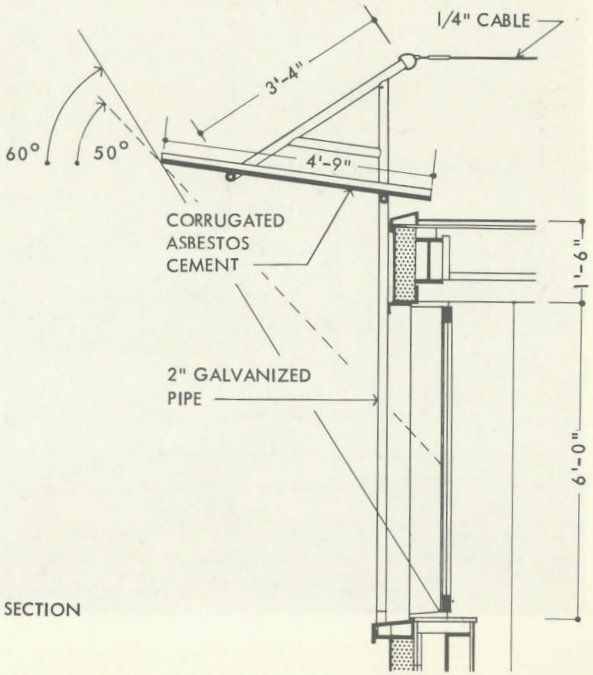






MARCEL BREUER, *Vassar College Dormitory, Poughkeepsie, New York*

The solution of the orientation of east and west windows is a cable stabilizer which holds in tension a galvanized pipe frame supporting the sunshades. Shade itself is achieved by sections of corrugated asbestos cement, which are spaced independently of each other. The result is a play of strips of light across the elevation.



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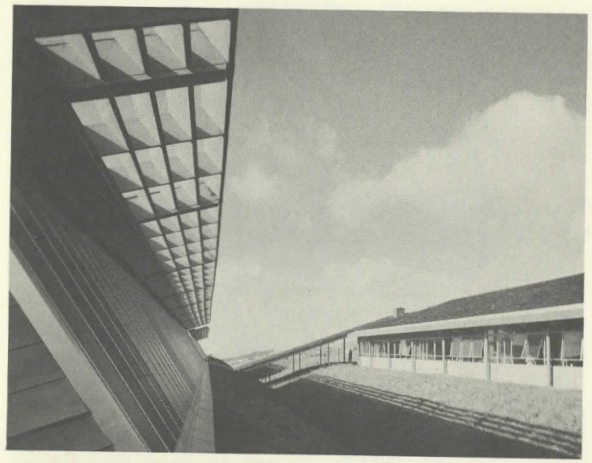
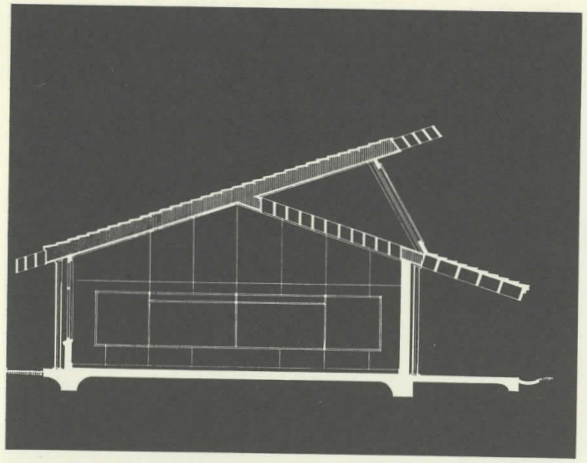
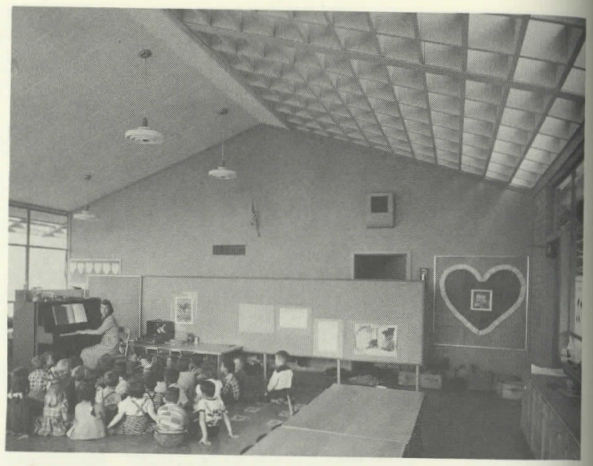
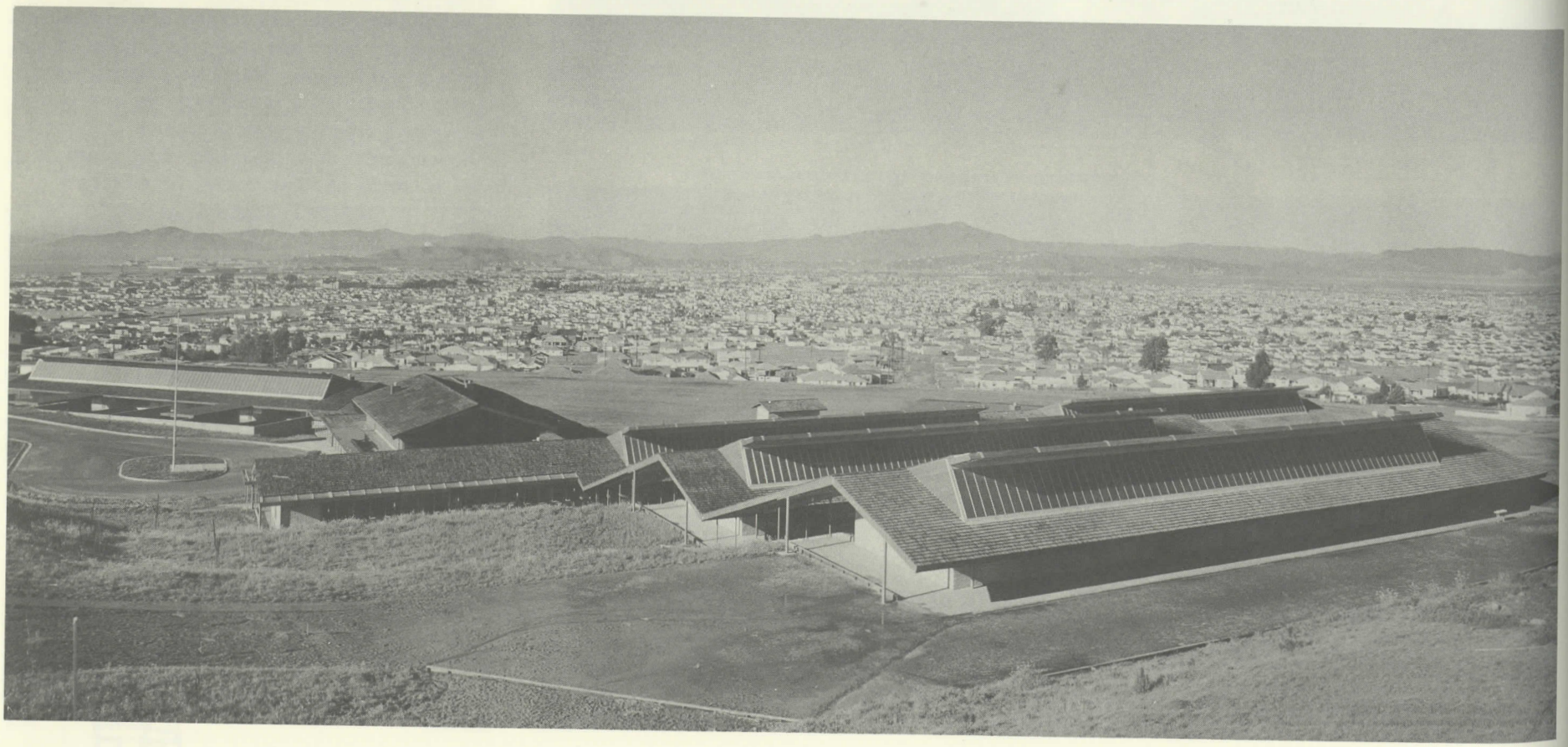
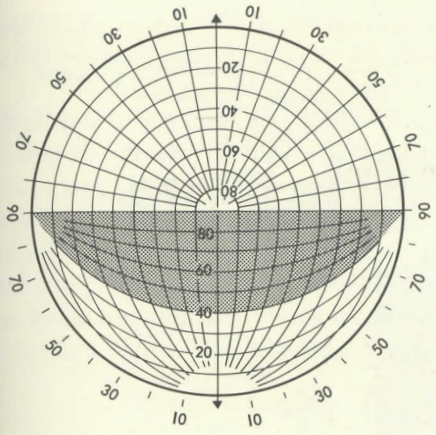


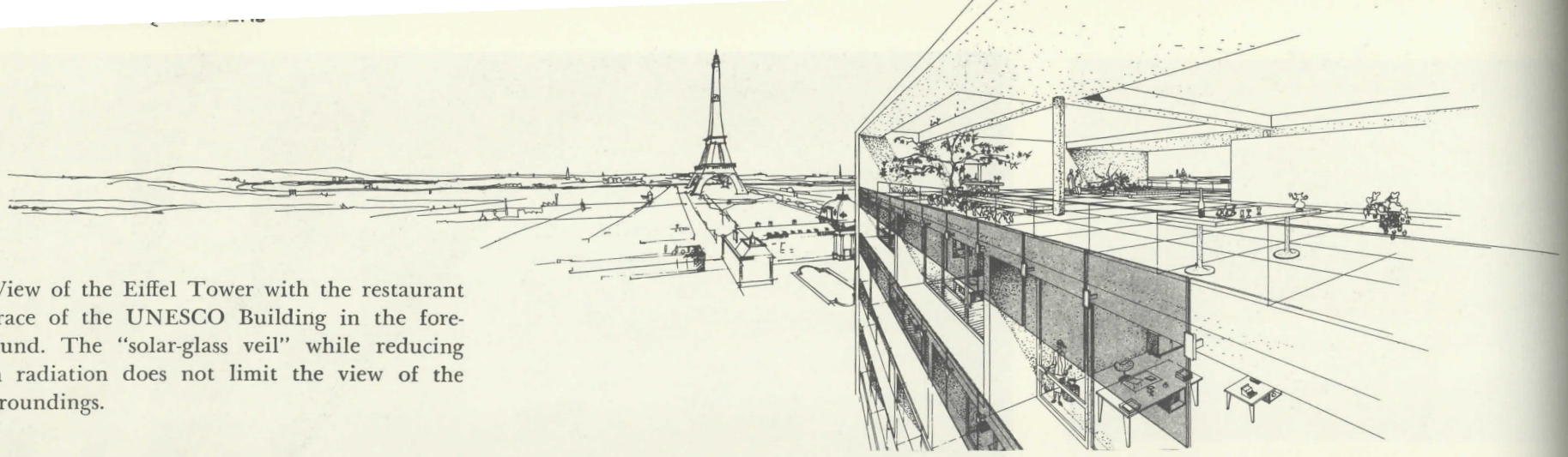




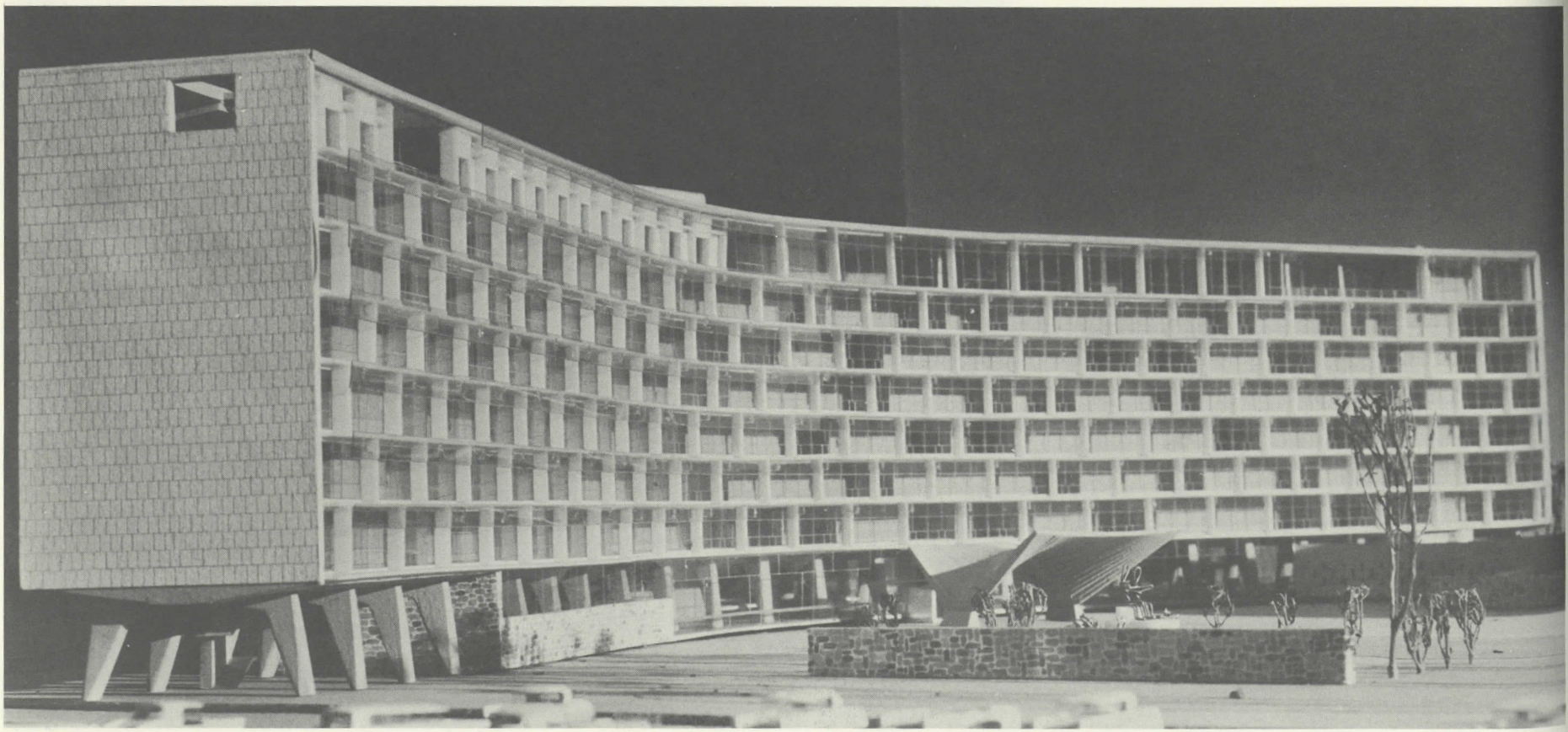




JOHN CARL WARNECKE, *Mira Vista Elementary School, El Cerrito, California*
The direct southerly sun is screened through fixed louvered eyebrows of wood, running along the upper edge of the skylights. North light was brought in above the corridors by what amounts to a studio skylight. Under these skylights large eggcrate ceilings are placed which cut off the direct view of the sky, and consequently the annoying glare. The skylights compose into interesting shapes with the wide overhangs as an aesthetic motif.



View of the Eiffel Tower with the restaurant terrace of the UNESCO Building in the foreground. The "solar-glass veil" while reducing sun radiation does not limit the view of the surroundings.



M. BREUE
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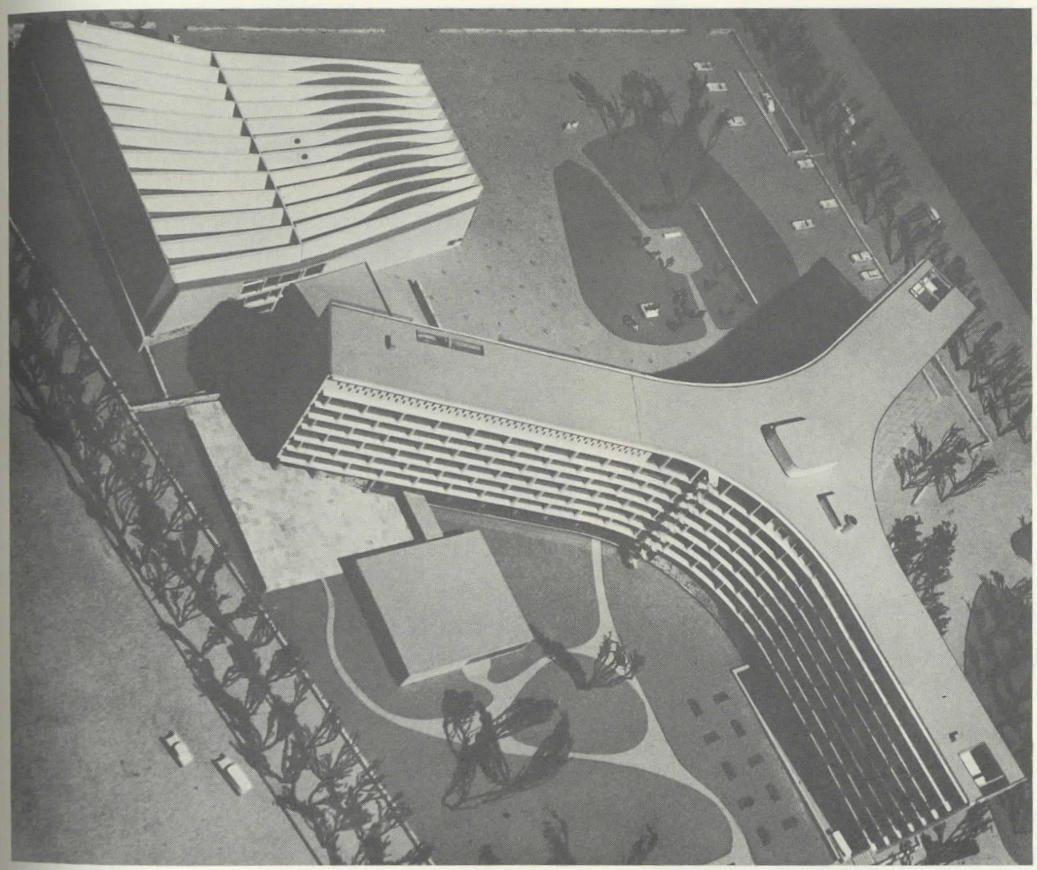
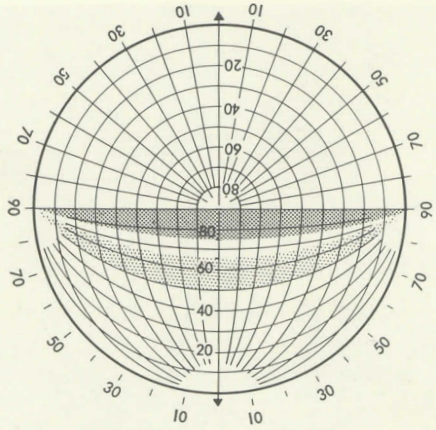
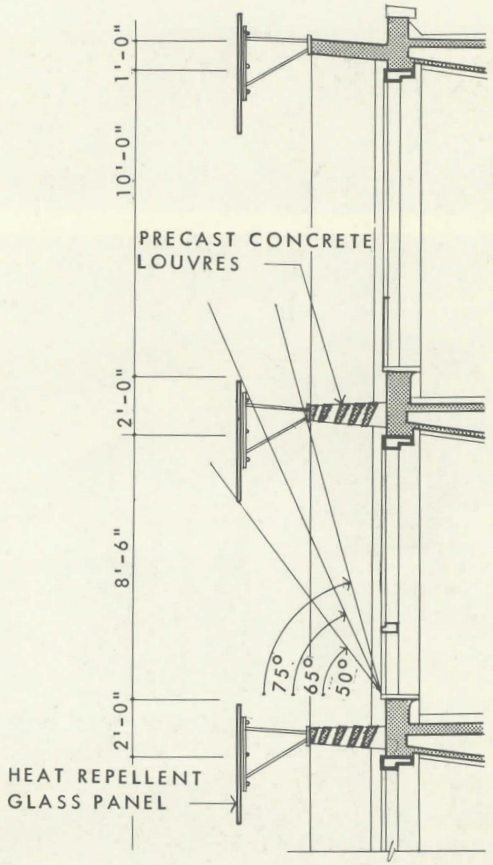
M. BREUER, P. L. NERVI & B. ZEHRFUSS, *UNESCO Headquarters, Place de Fontenoy, Paris*

The Y-shaped office building with rounded interior angles creates continuous, usable office space all along window walls with a central core to house all vertical communication and service facilities. The continuous glass facades are protected by a "veil" of solar glass which protects against heat, but permits undisturbed view and undiminished light. This shading device is adjusted to conform to the changing orientation of the facades by varying dimensions.

Two technical principles are introduced to solve the sun-control problem: first, the "eyebrow" sunshade is made of slats rather than solid panels, so that the heat that accumulates outside the window can escape upward before it affects the interior of the building; and, second, sheets of "solar glass" that absorb heat and reduce glare were introduced as part of the shading device.







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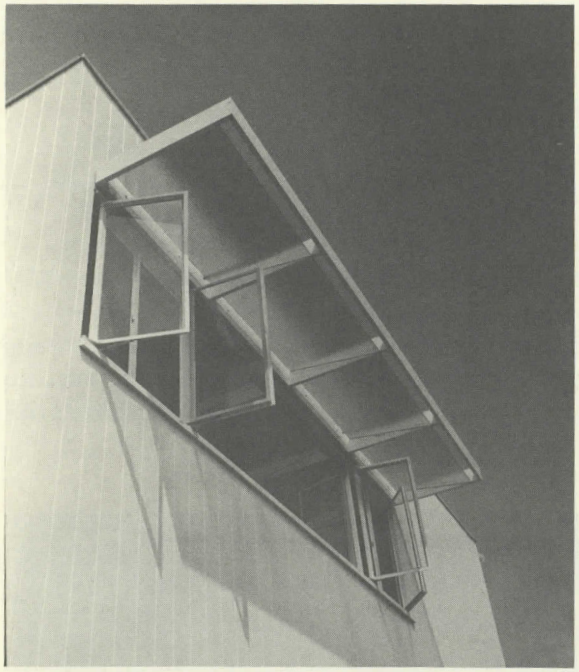
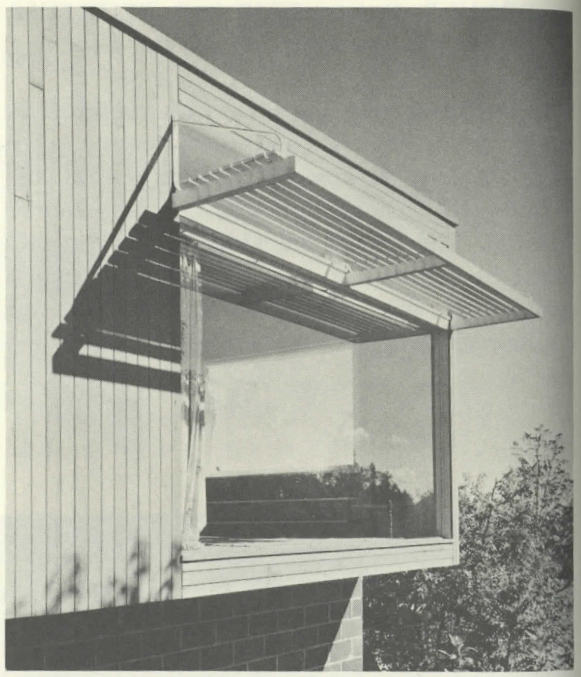


HORIZONTAL OVERHANGS

In residential constructions it is often desirable that instead of solid overhangs, sun protection should be achieved with devices which let light through. Here some solutions are shown, which are specially suited for southern exposures.

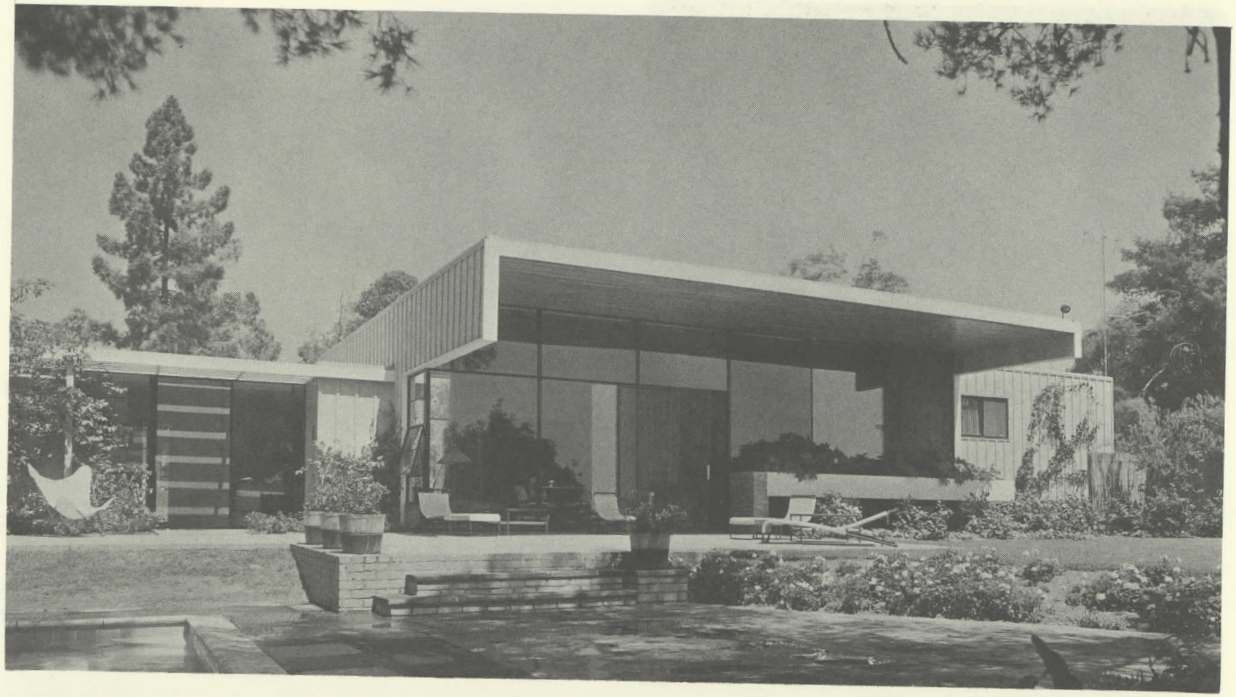
Left: Heat repellent glass in wood frame. George Nemeny, Frost House, Long Beach, N. Y.

Right: Wooden slats which will cut out part of sun's heat. The Architects Collaborative, Martin House, Six Moon Hill, Lexington, Mass.

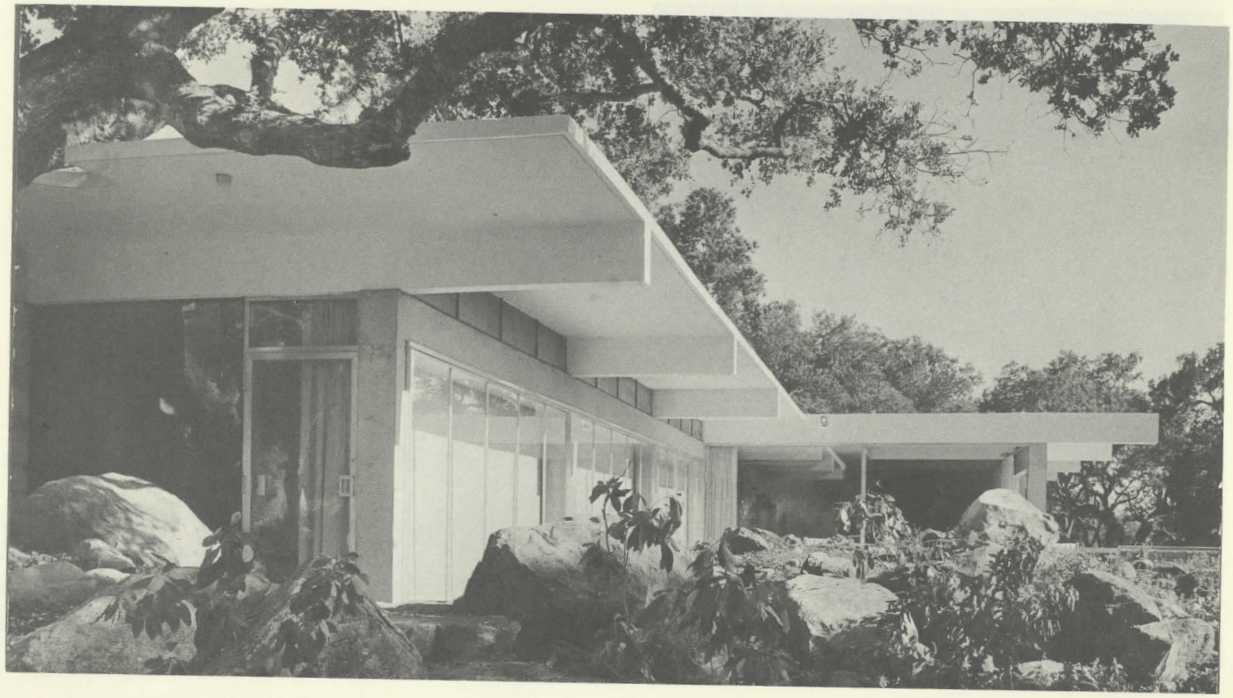


Left: Horizontal overhang with perforated material. Twitchell & Rudolph, Deeds House, Florida.

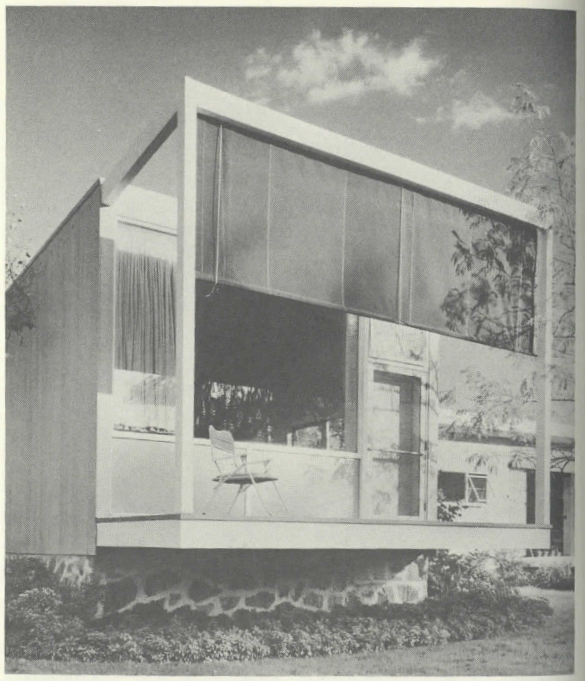
Right: Slanted wooden slats might give 100% shading while transmitting light. Harry Weese, Stendler House, Champaign, Ill.



HORIZONTAL OVERHANGS
This wooden horizontal overhang has vertical blinds at the ends, which drops deeper toward the west to secure more protection. George V. Russel, Pike Residence, Los Angeles, California.



The strongly emphasized concrete overhangs give a horizontal character to this residence. Richard Neutra, Tremaine House, Montecito, California.

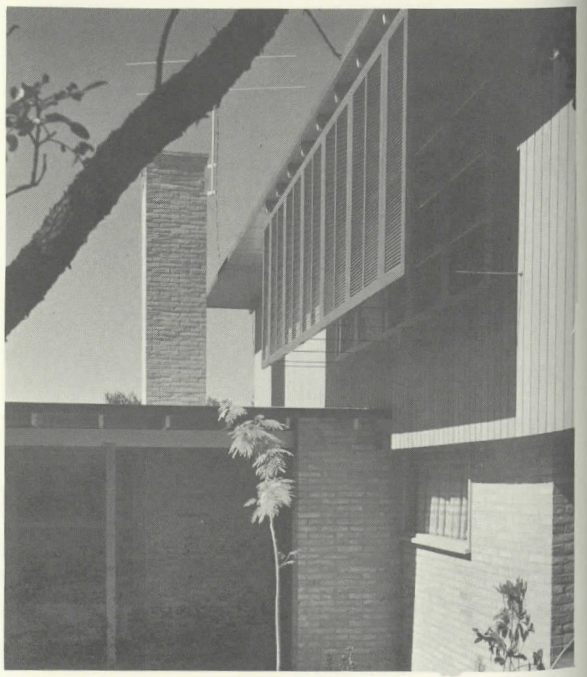


WESTERN PROTECTION

Toward the west devices parallel to the window surface give the best protection.

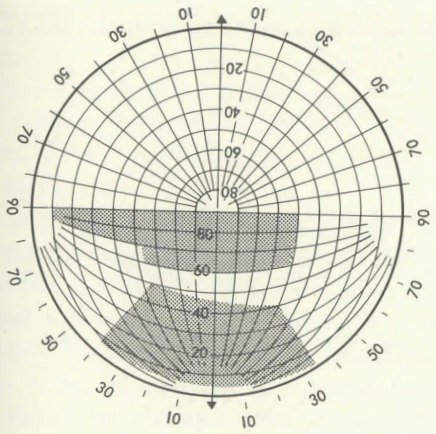
Left: Here a retractable bamboo curtain attached to a porch solves the problem. Anshen & Allen, Agee House, Oakland, California.

Right: Another solution with movable canvas awning, designed by Nemeny and Geller.



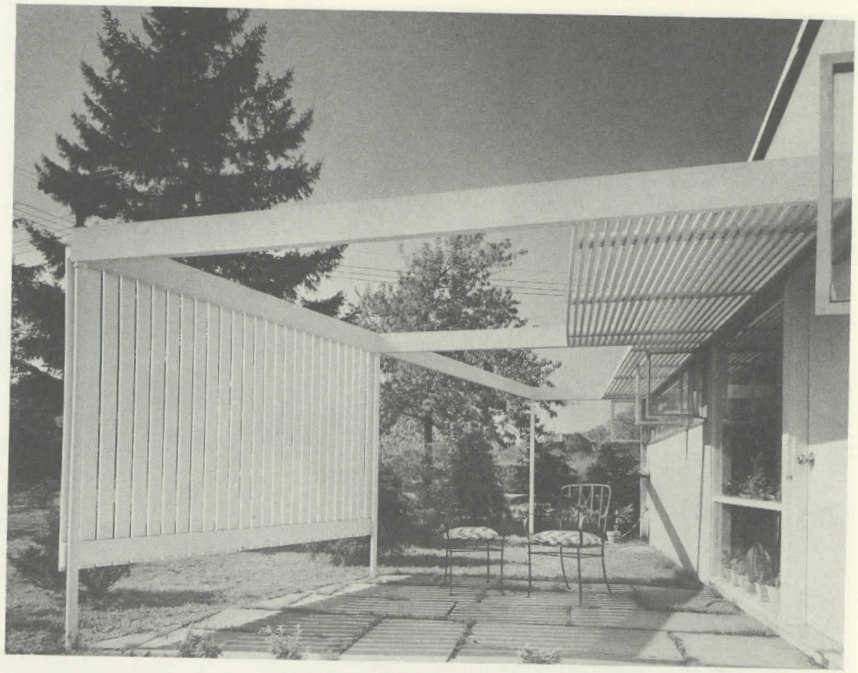
Left: The Agee house with the curtain lowered gives a different spatial feeling in the late afternoon.

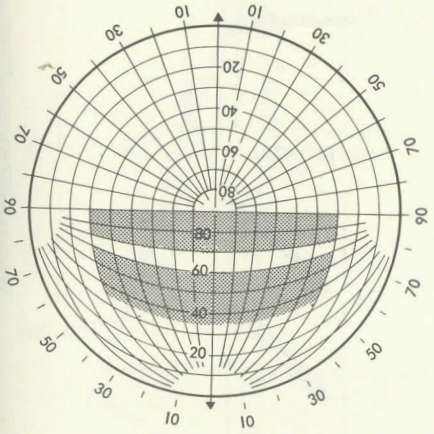
Right: A wooden jalousie set before the window combines shade with ventilation. O'Neil Ford & Jerry Rogers, Hixon House, San Antonio, Texas.



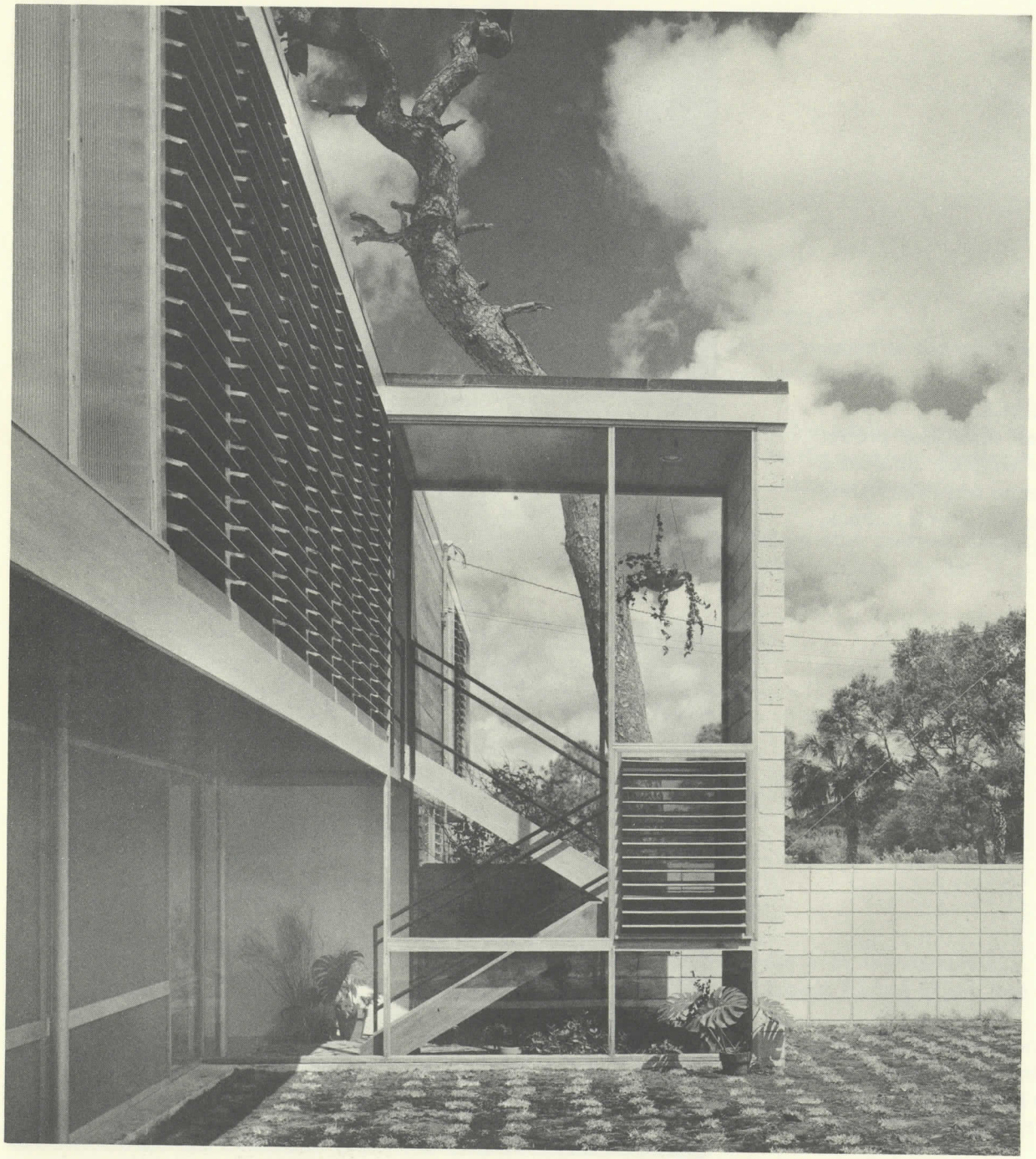
RESIDENTIAL SUN-BREAKERS 24

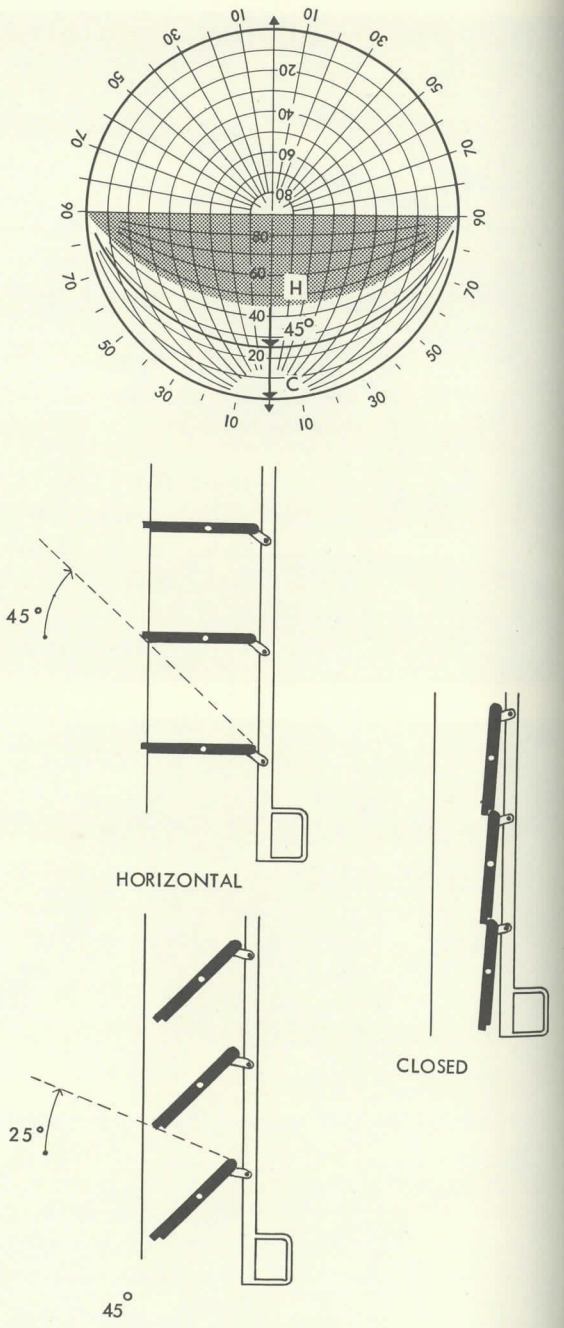
On the west side louvered sunshades protect living room glass. Beams support sunshades, brace fence and tie together to form interesting spatial composition. Sanders & Malsin & Reiman, Palley House, Scarsdale, N. Y.





A similar solution enhanced with bright color combinations. Masks are drawn from the middle point of the bottom part of windows. Charles Eames & Eero Saarinen, Entenza House, Santa Monica, California. 25



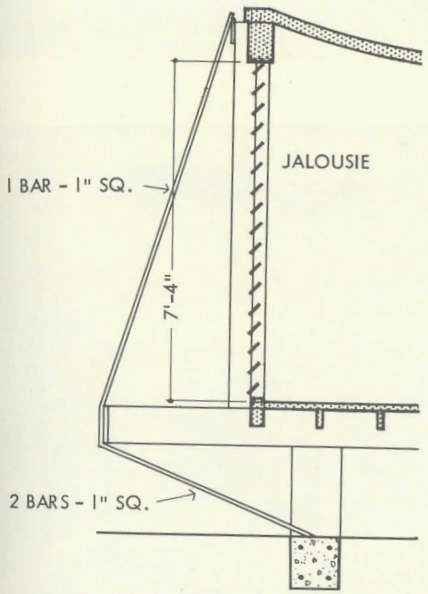


POSITIONS OF JALOUSIE

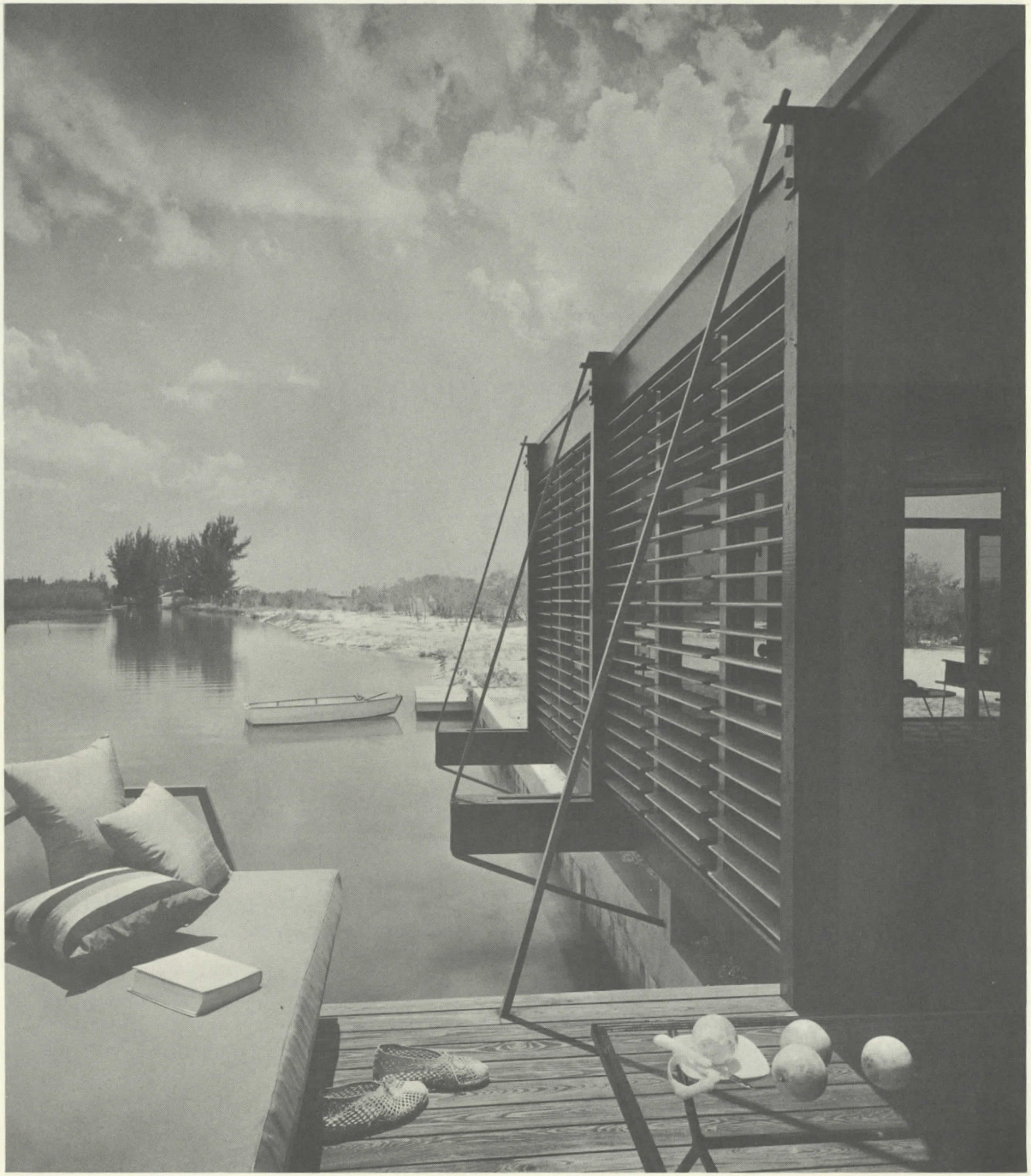
TWITCHELL & RUDOLPH, *Family Houses, Florida*

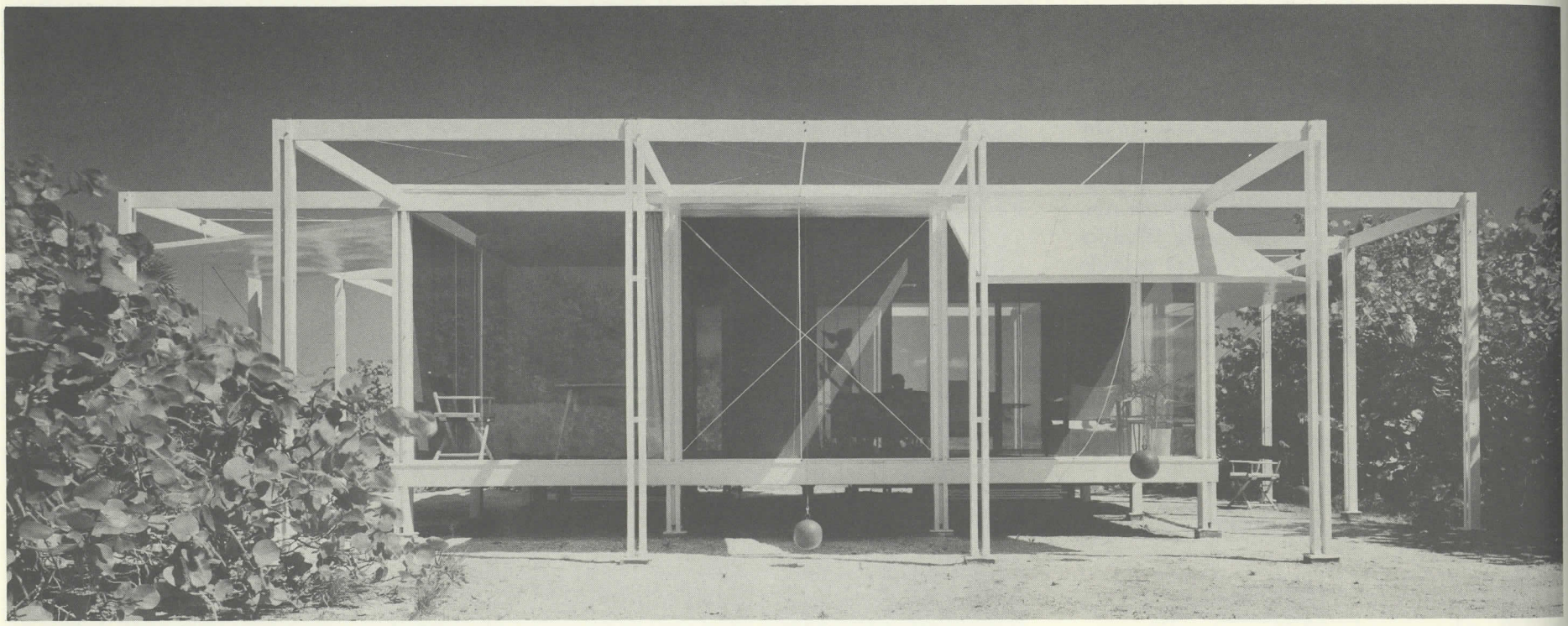
Both the Leavensgood house, opposite, and the Healey house have the same style and characteristics, built for the same region and by the same architects.

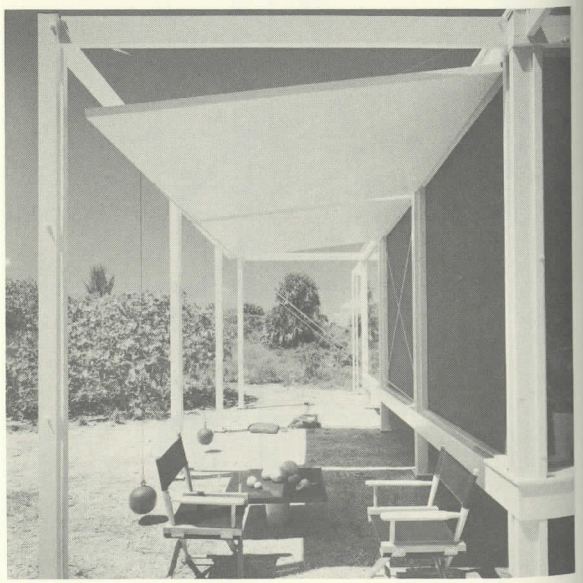
To take fullest advantage of the breezes from the southwest, and for protection from the sun, the houses are surrounded with glass jalousies or wood louvers. The movable louvers provide a variable shading ratio, which makes it effective in a hot climate in any orientation. The mask shows its characteristics in the different positions.

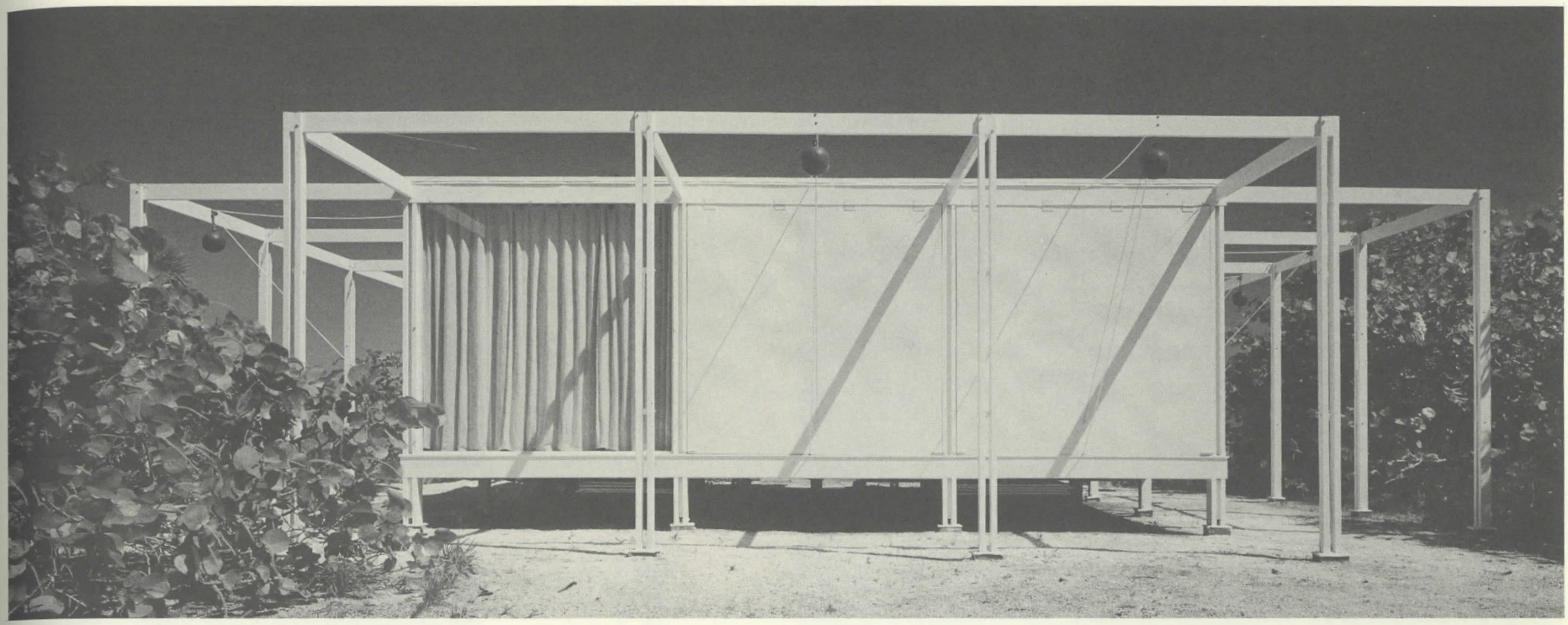


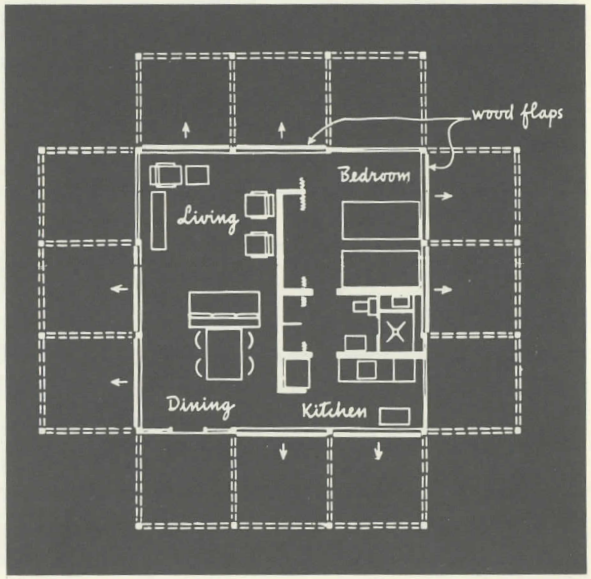
SECTION



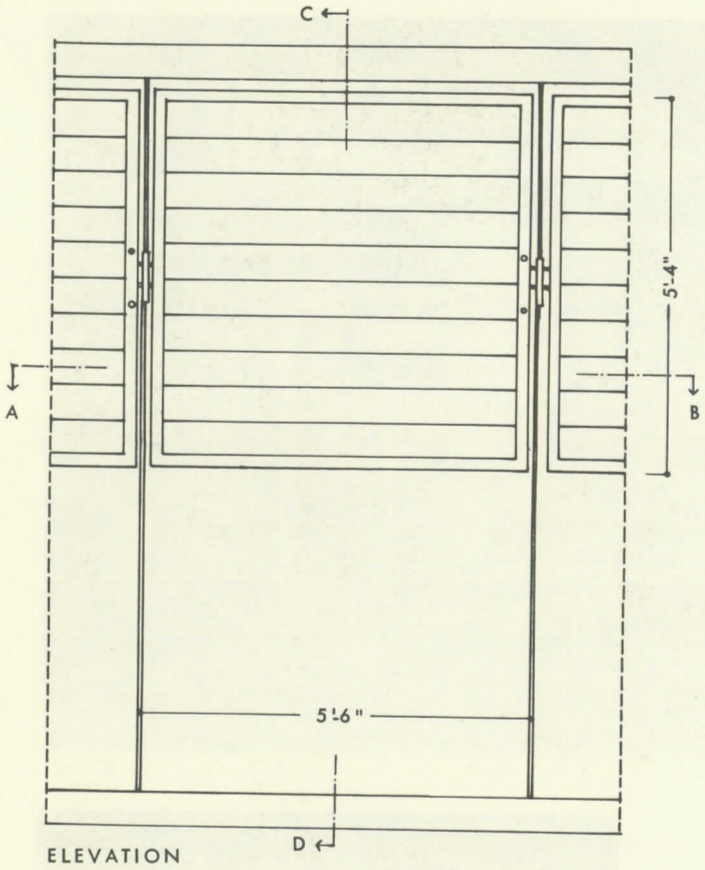




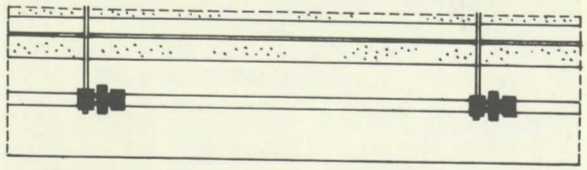




PAUL RUDOLPH, *Guest House, Sanibel Island, Florida*
This square house is made up of three equal panels on each side wall. One panel is of fixed glass (or it includes a door), while the other two have fixed outside screening combined with upswinging wood "flaps" counterbalanced with balls. The house may be quite closed with all panels louvered, or may be quite open if the flaps are raised. The flaps act as shading devices when raised, creating an open, airy, and shaded living space.



ELEVATION

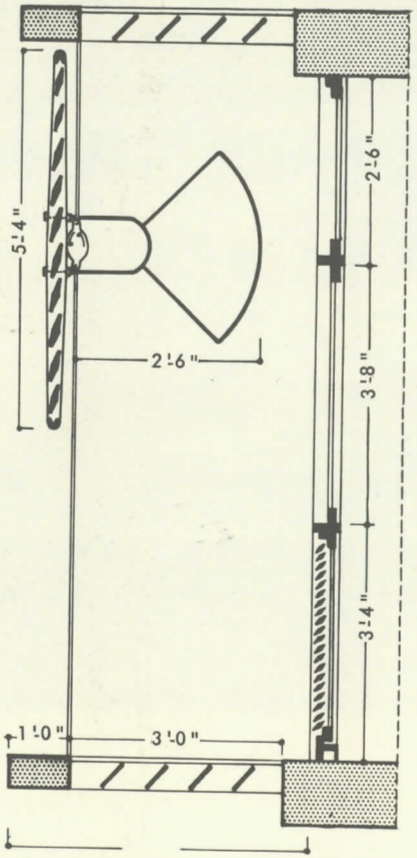


SECTION A-B

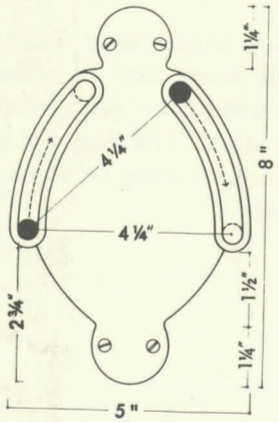
The detail drawings show the elevation, a horizontal and a vertical section through the shading device. In the drawings the movable louver is shown in vertical position.

The positioner, which enables fixing the louver in any of the three positions by a manually operated handle, is drawn in a larger scale.

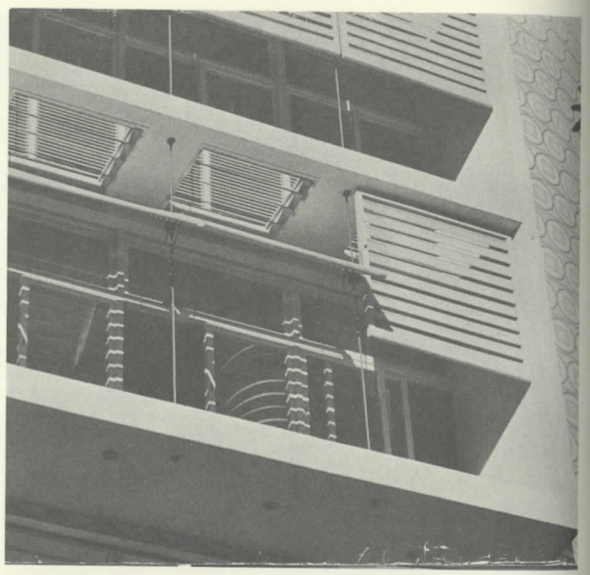
DETAIL DRAWING OF LOUVRES

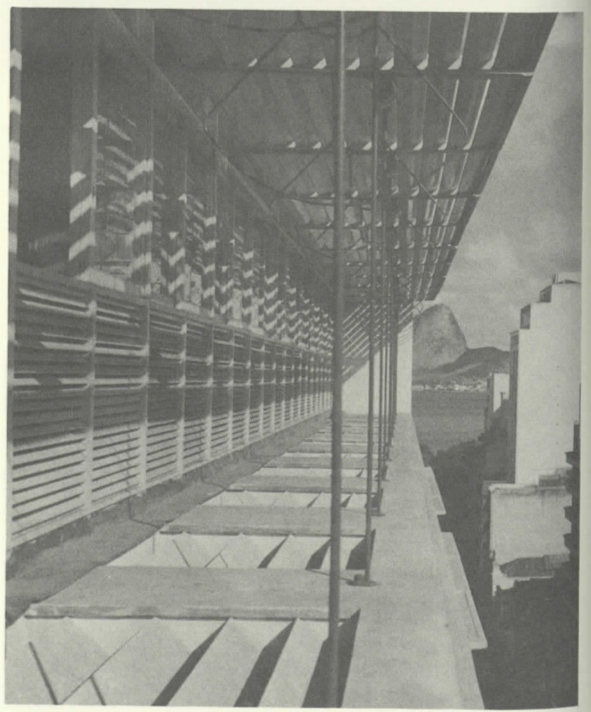


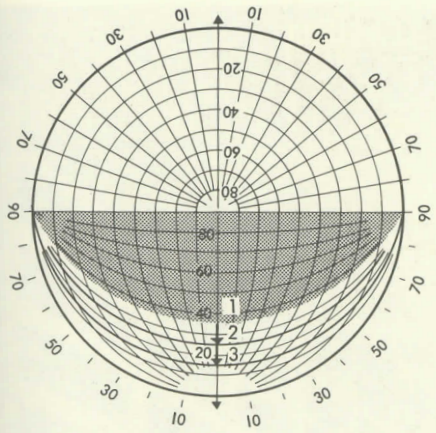
SECTION C-D



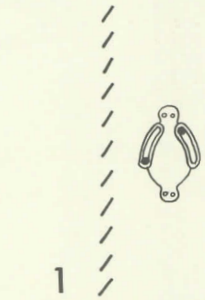
DETAIL OF LOUVRE POSITIONER



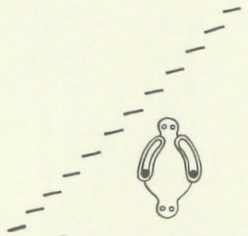




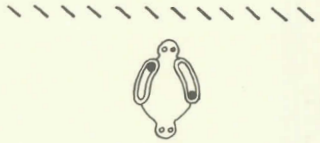
POSITIONS:



1
VERTICAL



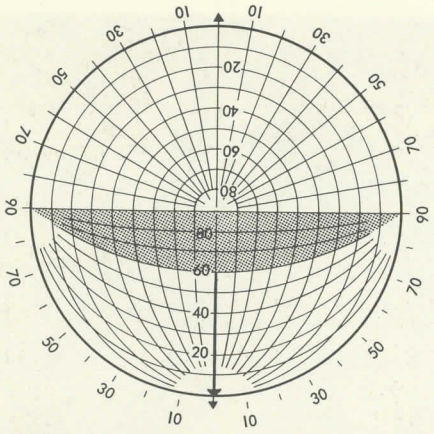
2
45° DEGREES

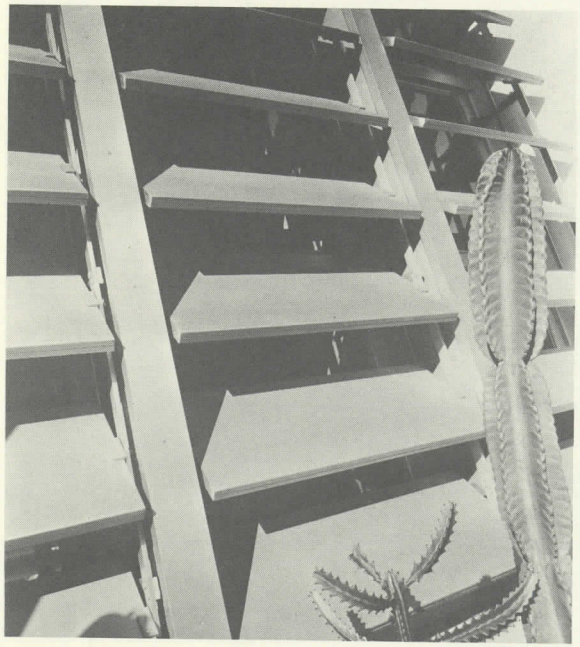


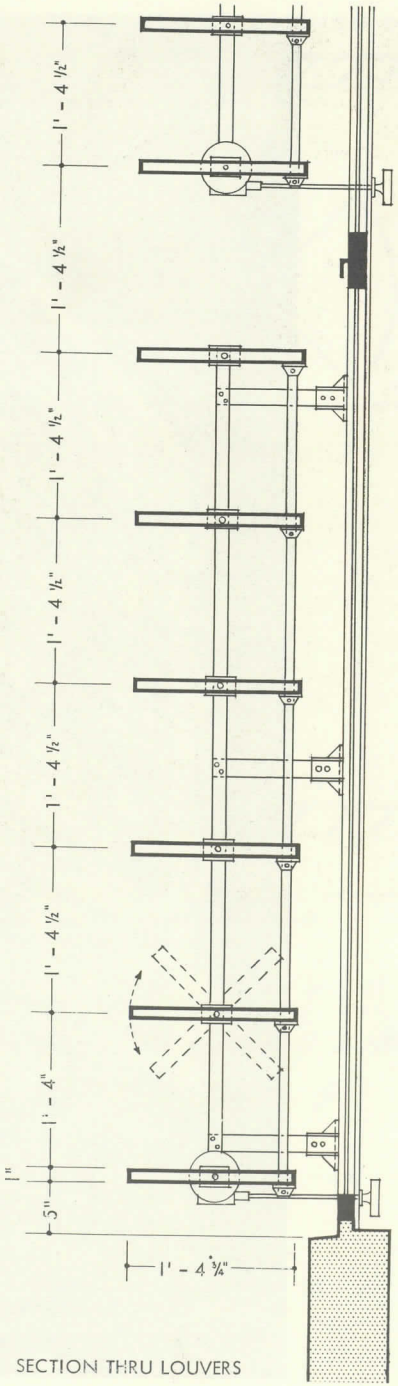
3
HORIZONTAL

M. M. M. ROBERTO, *Seguradoras Building, Rio de Janeiro, Brazil*

The elevation of the building which receives the most sunshine is evolved in practically two layers; one is the inner side with windows, which is the actual enclosure, and the other three feet before it, which is the visual one, serving as a filter against the sun's heat. The changeable position of the movable louvers results in a variable and playful character throughout the day. The horizontal shade is the continuation of the floor slab made of reinforced concrete. It is formed as a frame with inserted asbestos louvers, so that the heat accumulated outside the wall can escape upward. The manually operated movable louver can be fixed in three positions securing different shading characteristics, as shown on the mask.

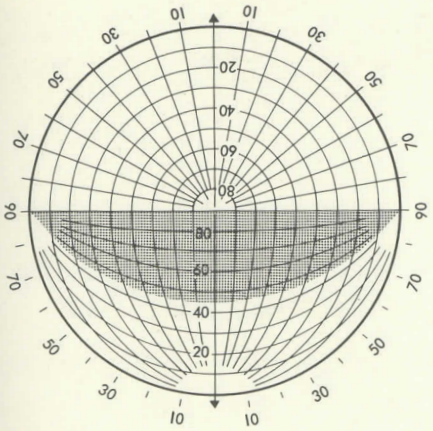


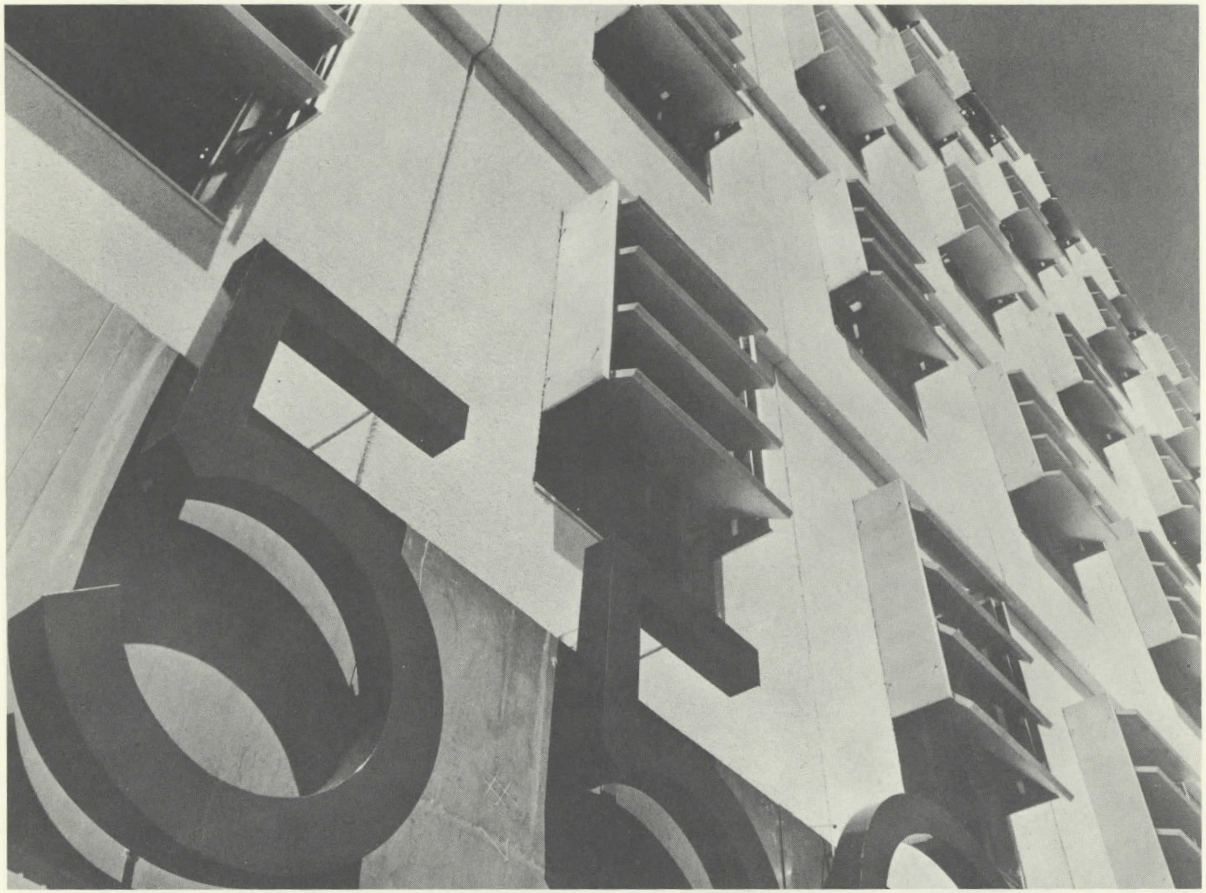




SECTION THRU LOUVERS

IGOR B. POLEVITZKY, *Arthur Murray Studio, Miami, Florida*
This one-story building on its whole entrance elevation is protected by adjustable horizontal louvers. The entire construction is made of aluminum in a system whereby the louver blade is adjusted by an inside screw.

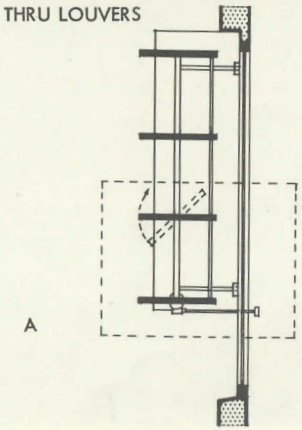




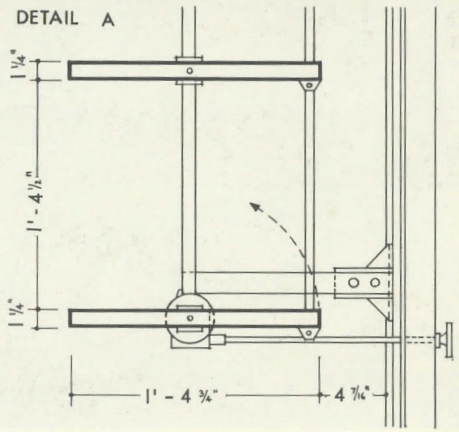
ROBERT LAW WEED & ASSOCIATES, *"550 Building," Miami, Florida*

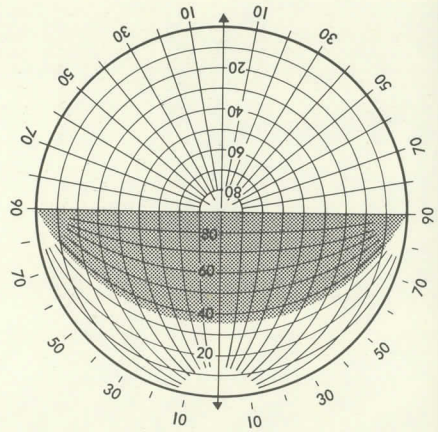
A system of operating aluminum louvers placed on the east, west, and south facades, and fixed vertical fins at the western edge of openings on the north wall minimize the entrance of direct sunlight, thereby reducing the air-conditioning load. The separately placed thermal "vista windows" produce a pleasing textural surface.

SECTION THRU LOUVERS

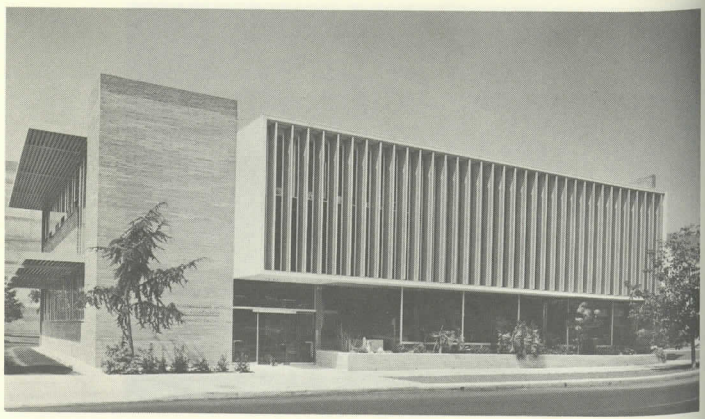


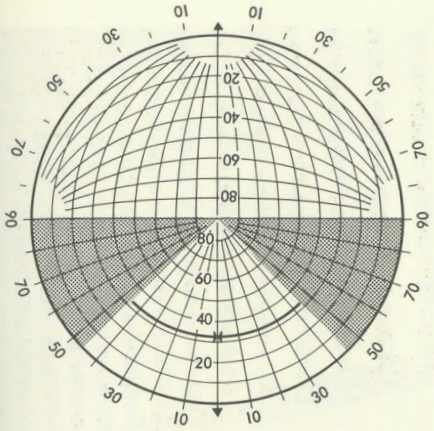
DETAIL A



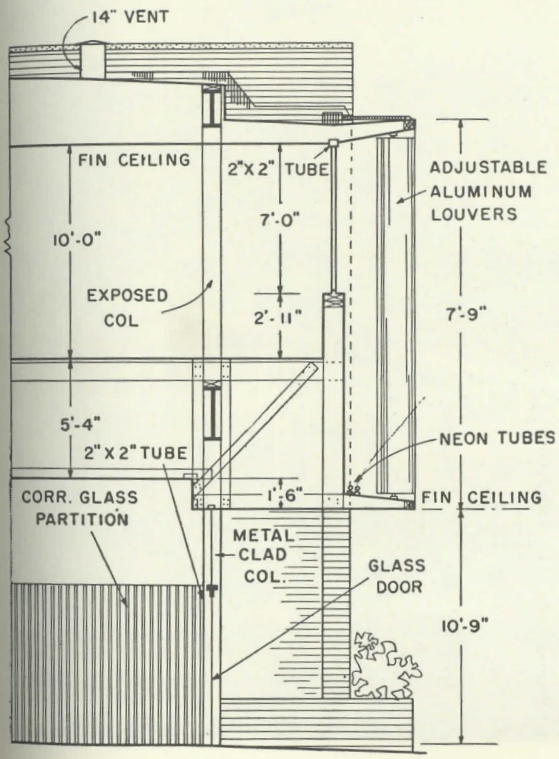


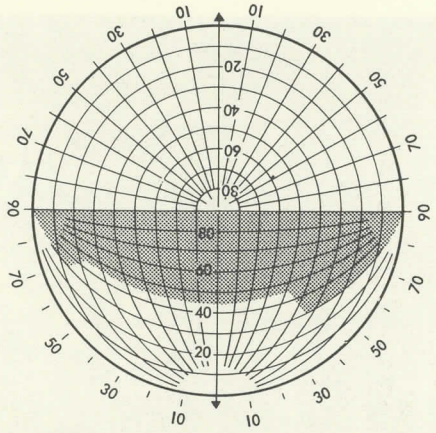
RICHARD NEUTRA, *Northwestern Mutual Fire Association, Los Angeles, California*
The building has two types of shading devices on its elevations, functionally applied according to their orientation. On the south side, steel supported deck and roof overhangs control sunlight and make extensive window areas practical. On the long eastern elevation, vertical louvers control the morning sunlight. The vertical aluminum louvers are designed to cover both the window and wide spandrel areas, and are therefore larger than their strict function demands. However their 17'0" height does serve a legitimate purpose of design. Had the louvers





covered only the windows, the spandrel facing plus the ground floor glass facade would have complicated the small building front with three separate areas. As it is, the louvered facade decorates and simplifies the building.



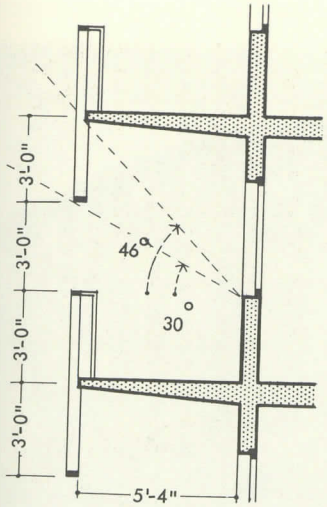


LUCCICHENTI & V. MONACO, *Apartment in Tarente, Italy*

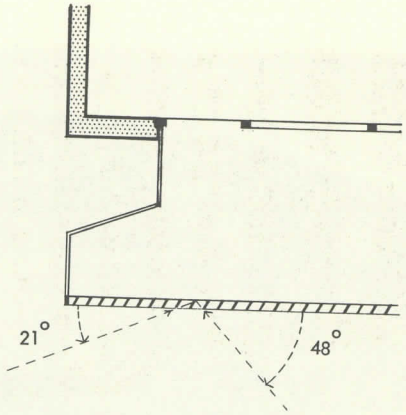
This apartment house which in itself has a very schematic architecture achieves an airy and interesting expression by the placing of a screen before it. A prefabricated sun-screen, constructed of lightweight concrete and attached to the vertical edge of the overhang, protects the corridor and glass openings from the intense southwestern sun. The six-foot-high screen has a rectilinear frame with fixed louvers, which allows for air penetration but interrupts sun-rays. The horizontal strips of sun-blinds are placed in such a manner that they do not interfere with the marvelous view.

The screen for the elevation is planned so that the upper part serves as a railing and the lower half as a shading device in combination with the horizontal balcony.

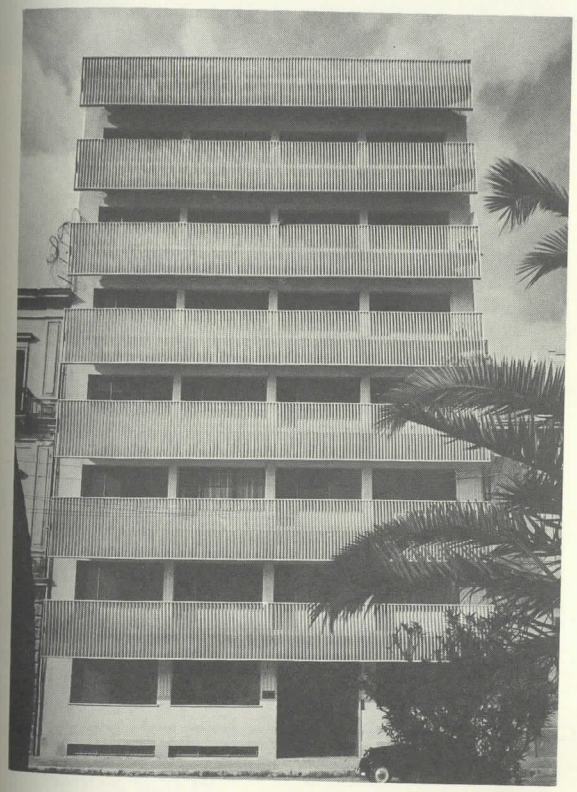
The vertical elements are slanted in an angle which gives an asymmetrical character for the shading mask.

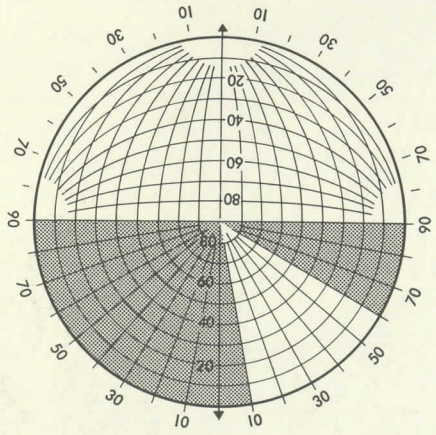


SECTION



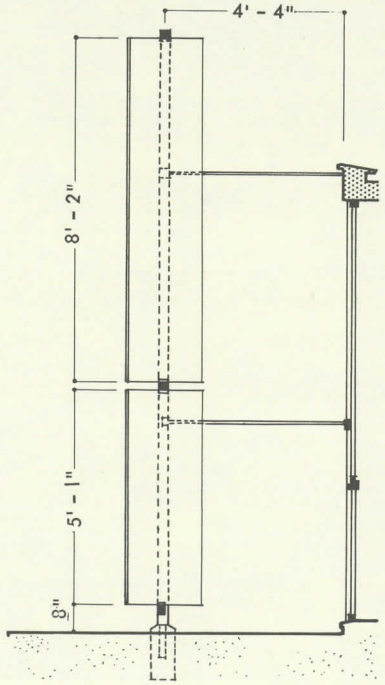
PLAN



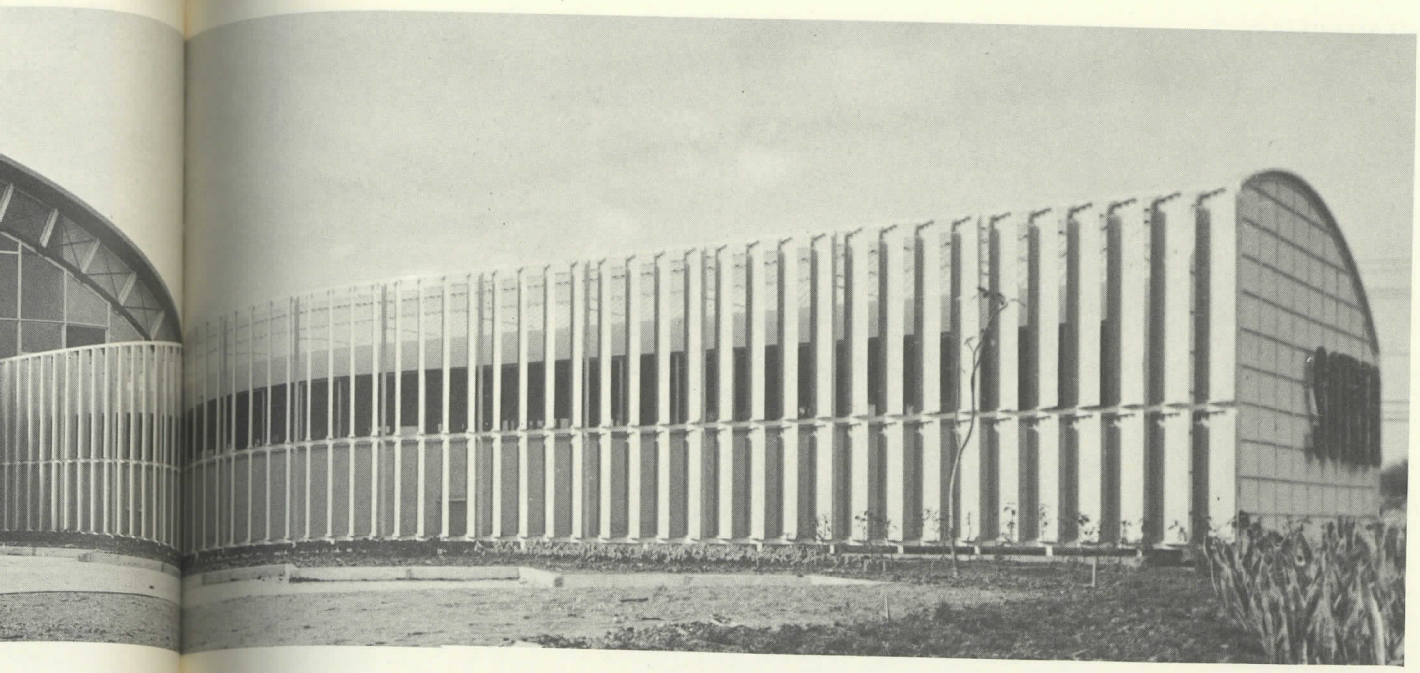


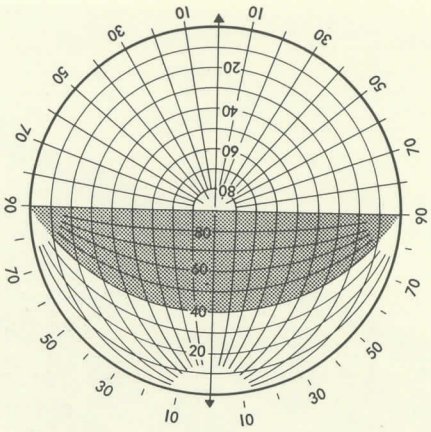
M. M. M. ROBERTO, *Caterpillar Industrial Building, Rio de Janeiro, Brazil*

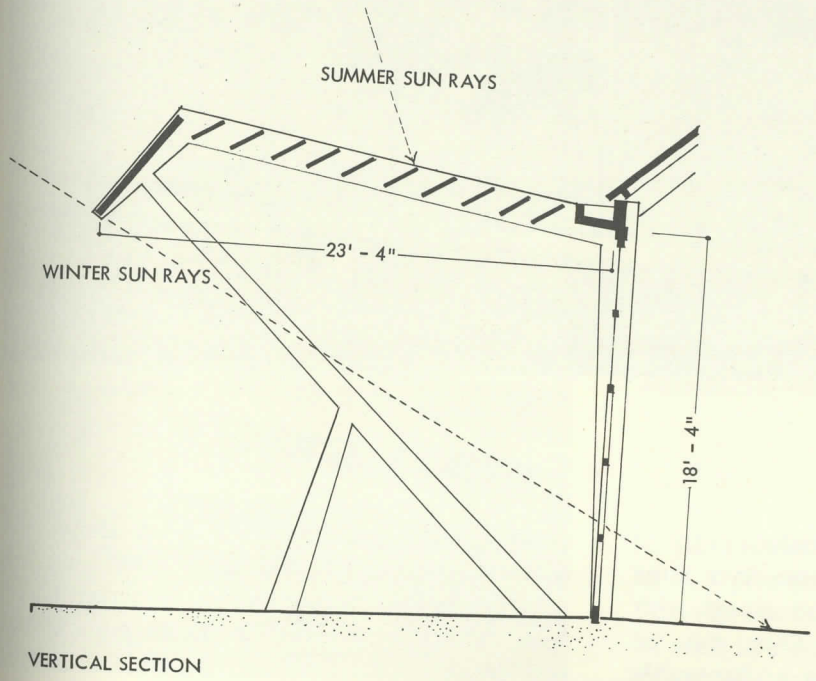
The mild climate of Brazil allows the ground level to remain unenclosed as an open air exhibition space for farm machinery and equipment. The sun-baffles of each of these wings rivals in interest the glass and gallery pattern of the main span; heat and direct sunlight is kept from the vulnerable north side of the workshop by a tilted canopy, 21 feet wide, with fixed louvers and diagonal bracing. Both the warehouse and the office wings are equipped with movable vertical fins of corrugated asbestos. In addition to these structural sun-shields, the offices and enclosed visitors' areas are to be air-conditioned.



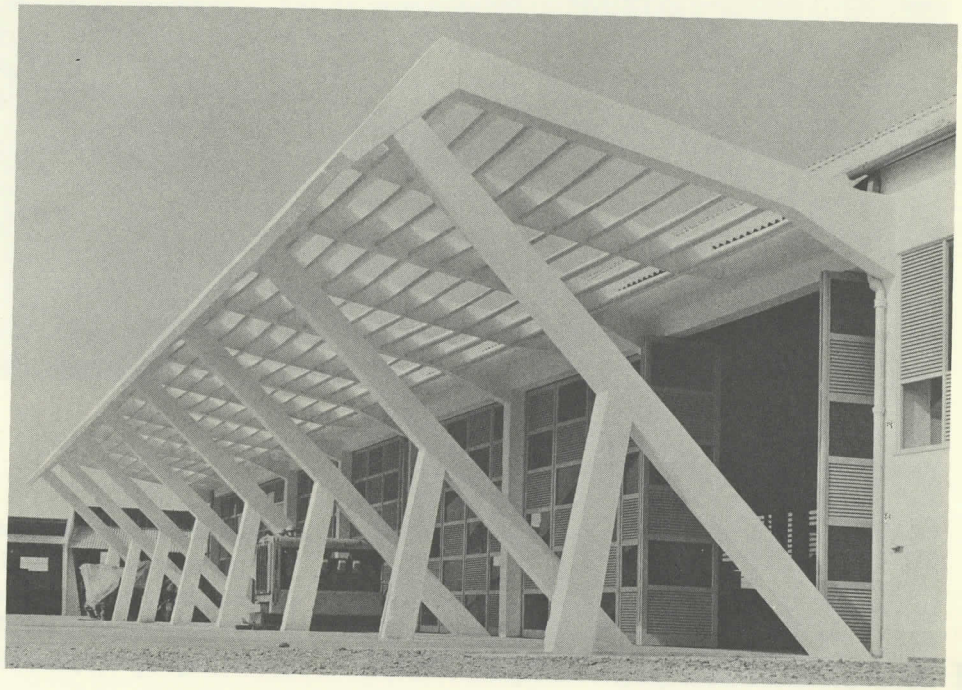
SECTION SHOWING VERTICAL FINS

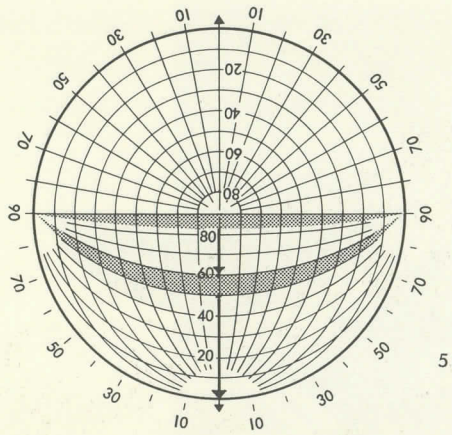


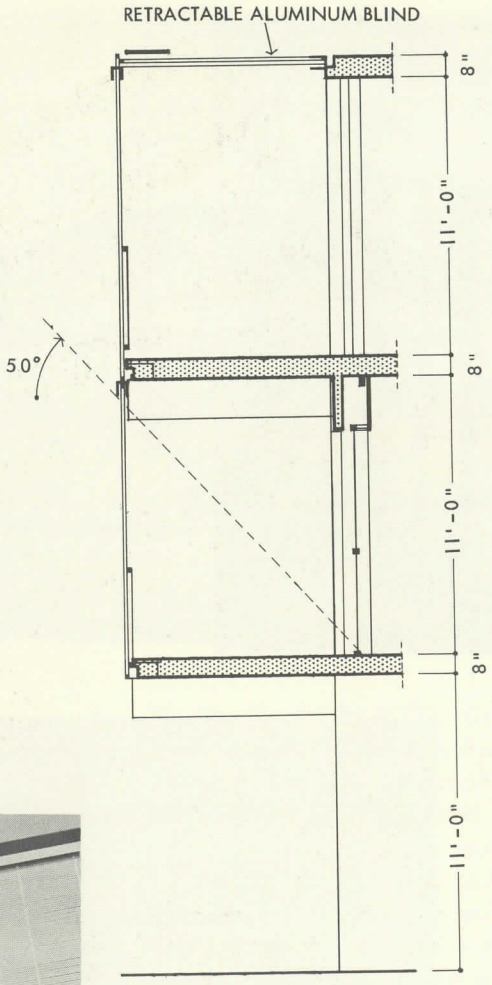




VERTICAL SECTION

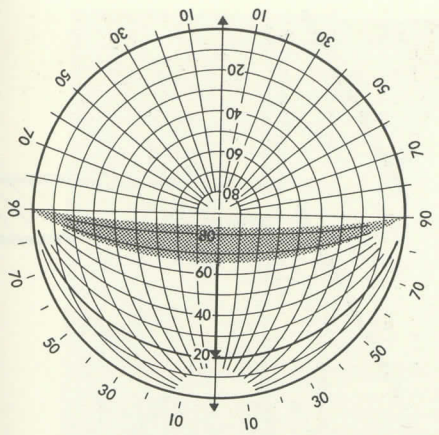


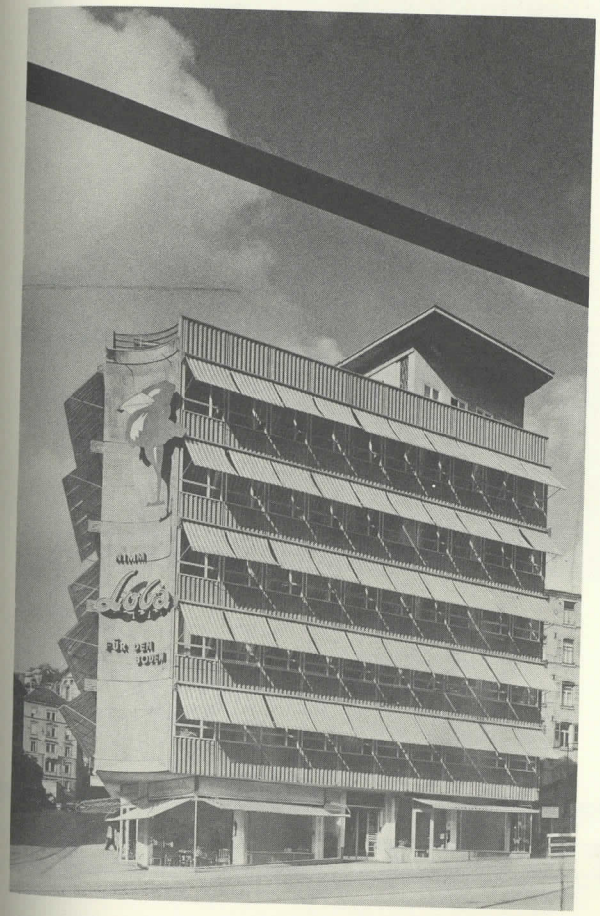


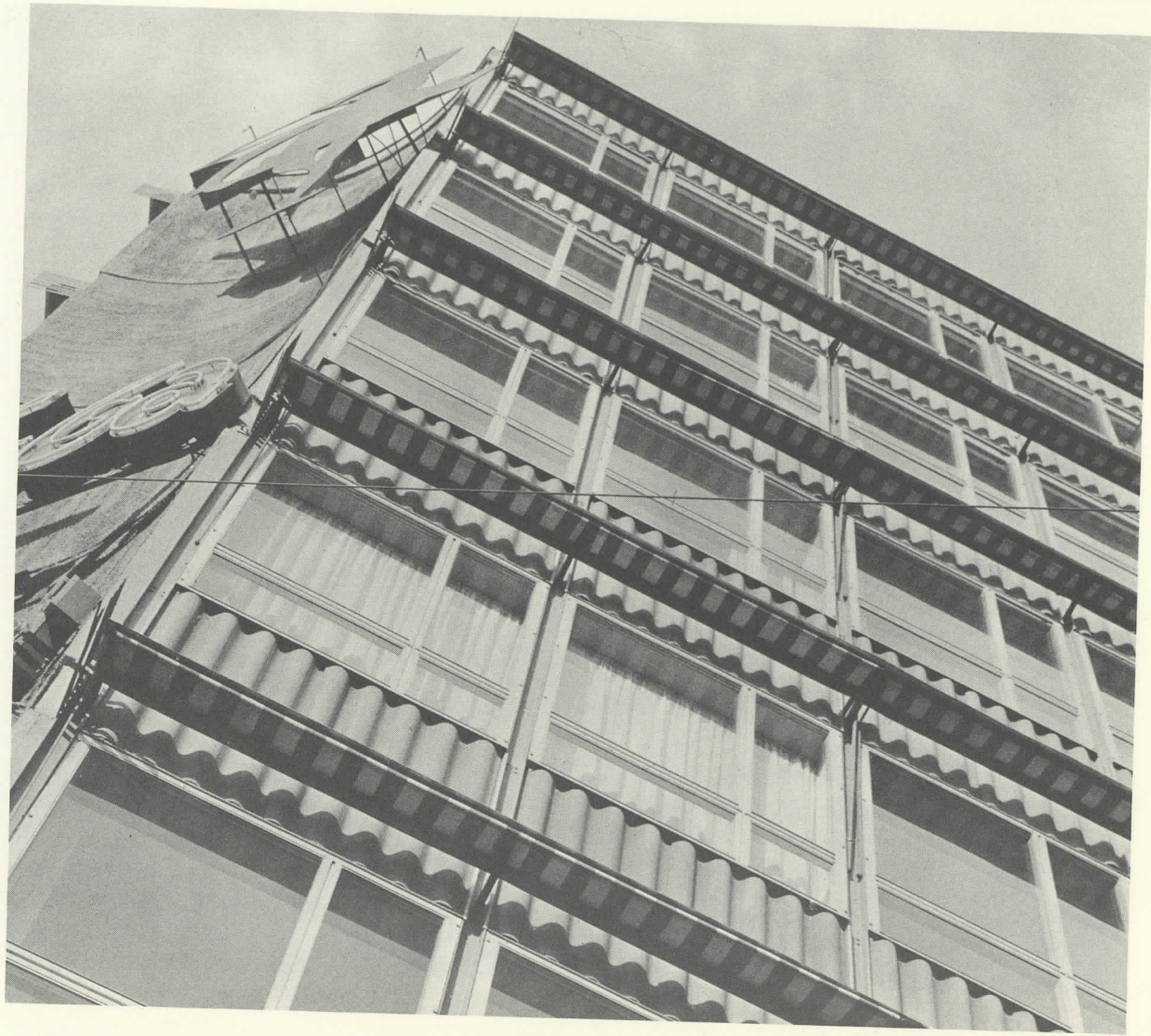


SECTION

GAI & MORO, *Villa in Alassio, Italy*
The two upper floors of this house have large porches, which can be opened or closed with retractable aluminum blinds. They can be moved separately in units, giving a changeable facade to the building. The mask shows the characteristics of the top floor with retracted louvers; only the fixed elements are shown therefore, the arrows pointing to the extreme closed position.





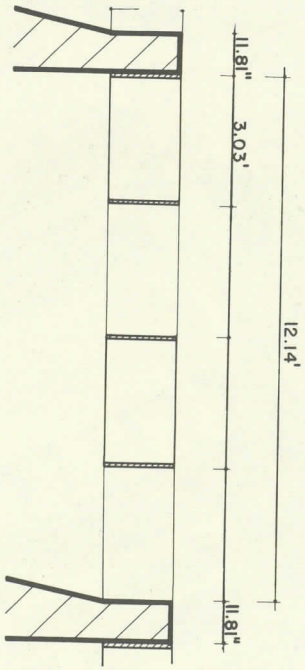


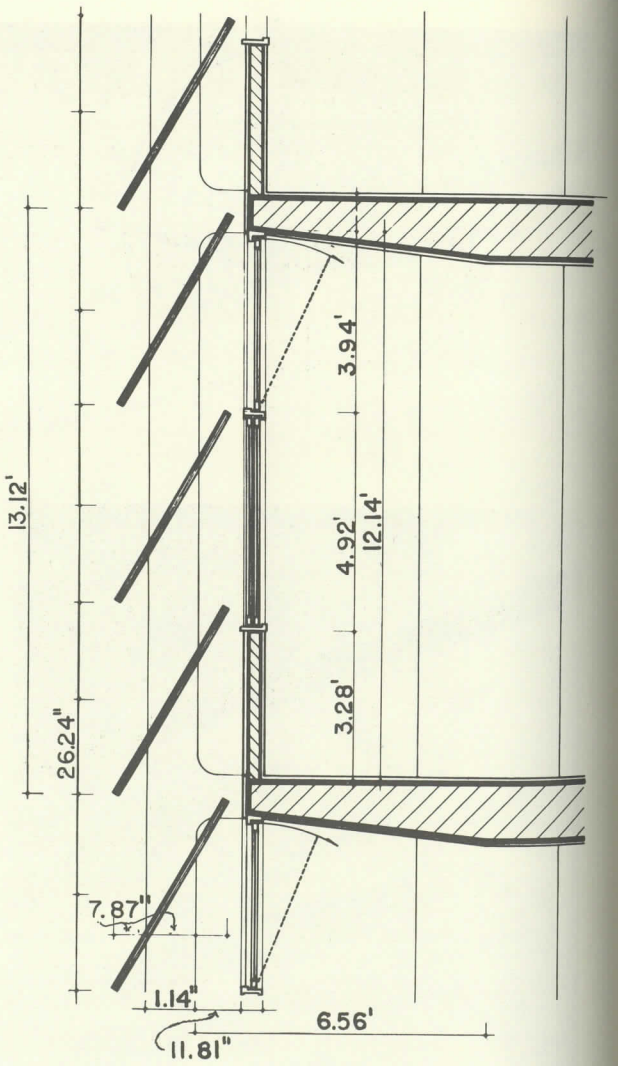
R. GUTBROD, G. KARRER, O. BESENFELDER, *Office Building, Stuttgart, Germany*
This office building is located on an acute angled lot with two elevations facing the streets. These elevations have ribbon-windows, protected by movable awnings. They are detached from the wall surface, so that the hot air that accumulates outside the window can escape upward. The character of the building changes throughout a day according to the projection of the awnings.

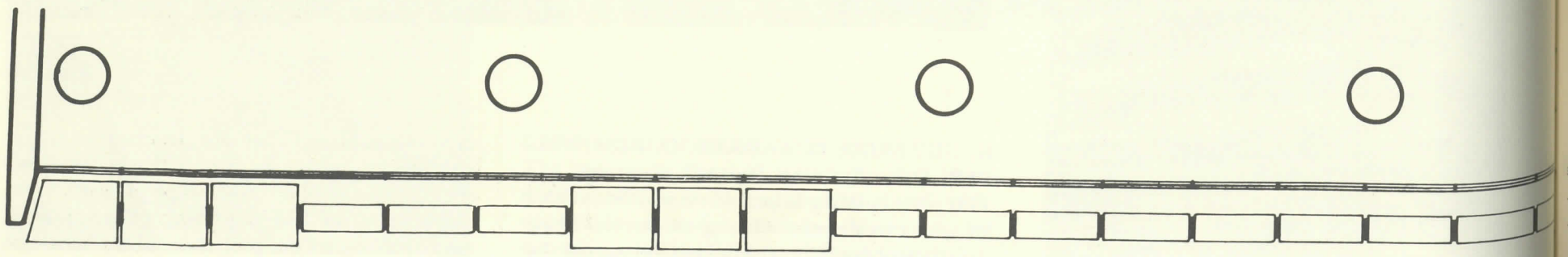
OSCAR NIEMEYER, *Emprezas Graficas O Cruzeiro Building, Rio de Janeiro, Brazil*
This building for a publishing house in Rio de Janeiro is located on a corner lot, facing north on the main street and east on the side street. The architecture of the building is characterized by the use of shading devices, which by their scaling have an integrated character throughout the design.

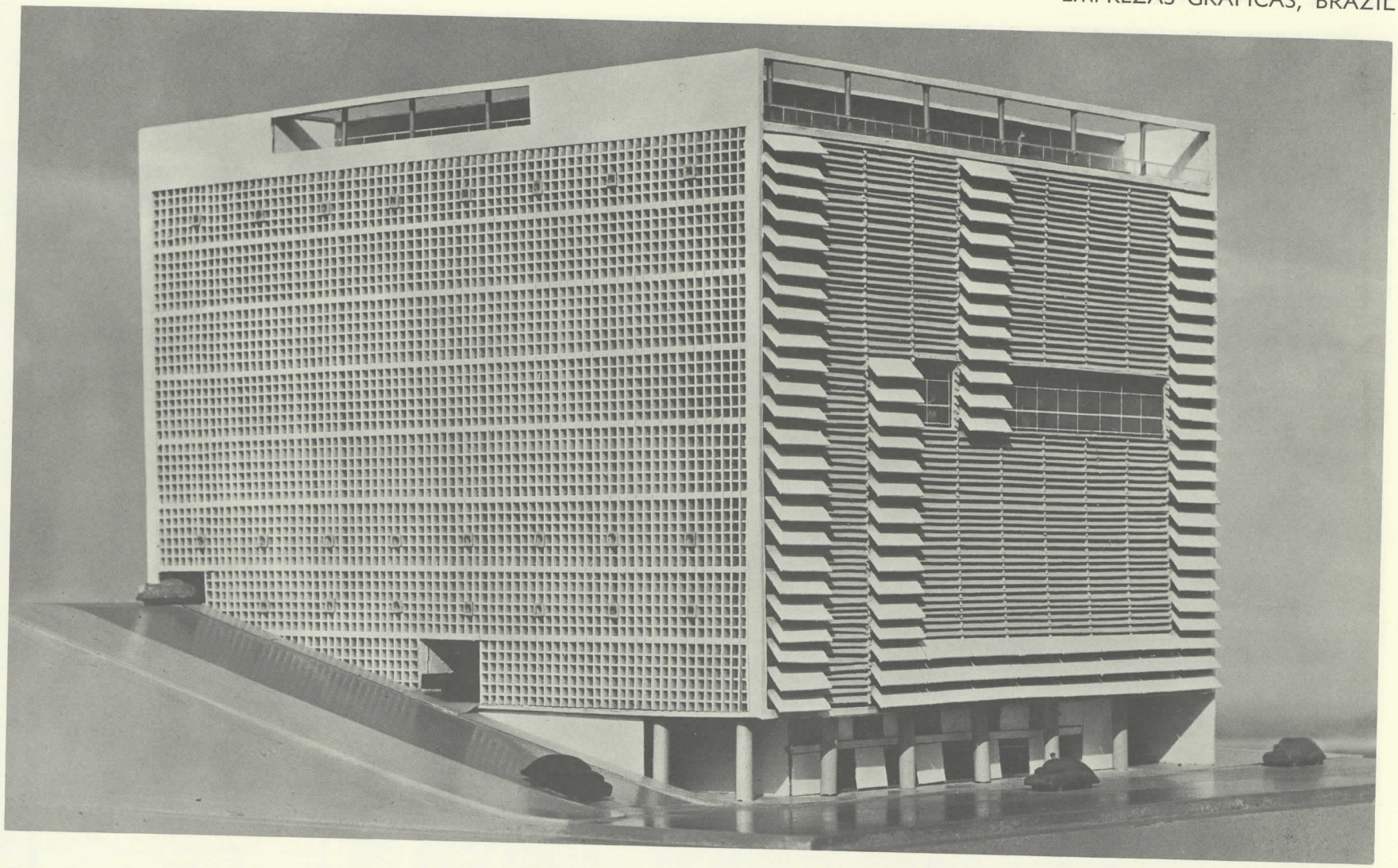
Because work in the plant begins early in the morning it was necessary to provide the eastern facade with protective screening. A fixed system of honeycomb concrete boxes forms an overall pattern on this facade.

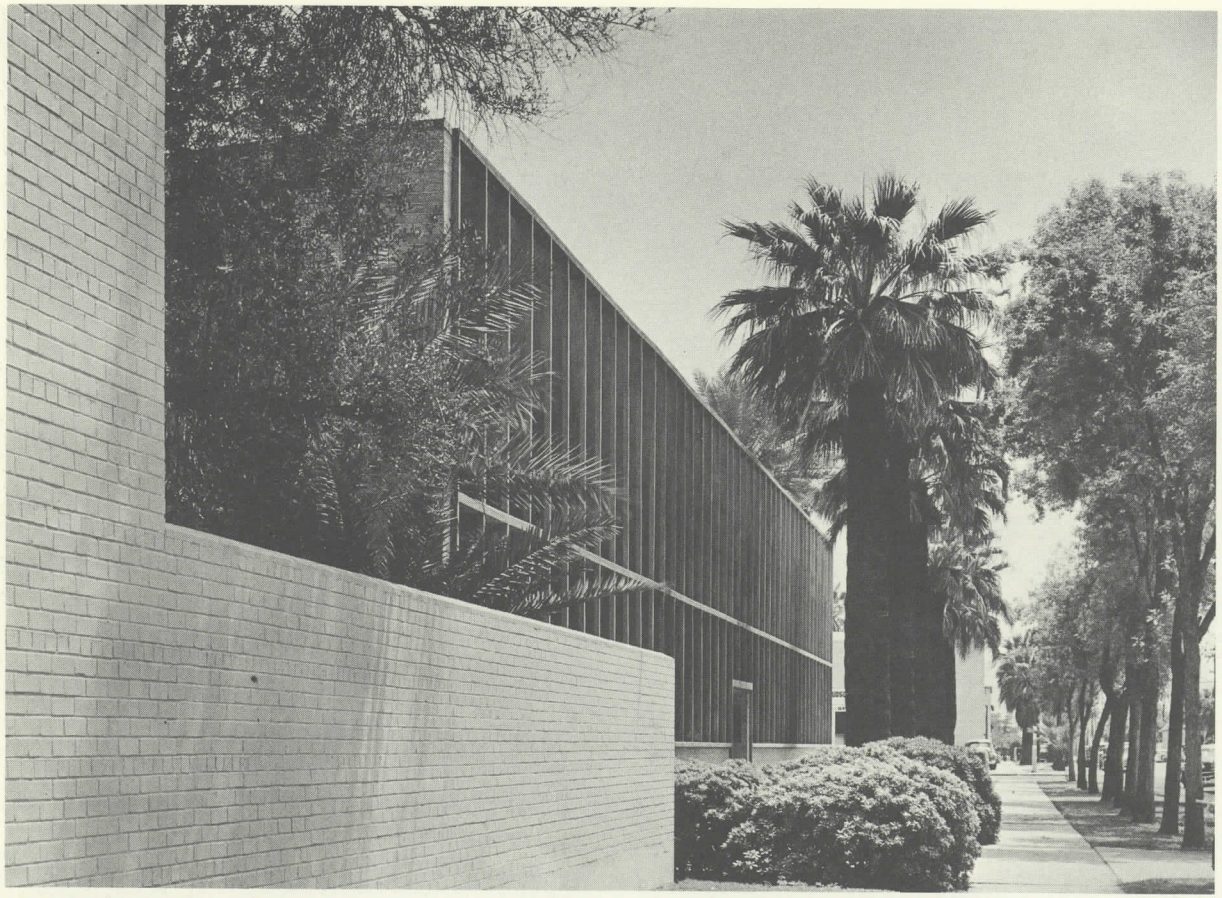
The sun-screen with adjustable horizontal louvers protects the north facade. The variation of scale of the device gives interest to the elevation. This possibility of changing the scale, but not the proportions, opens the field to use this motif in a playful manner, yet remaining functional in its concept.

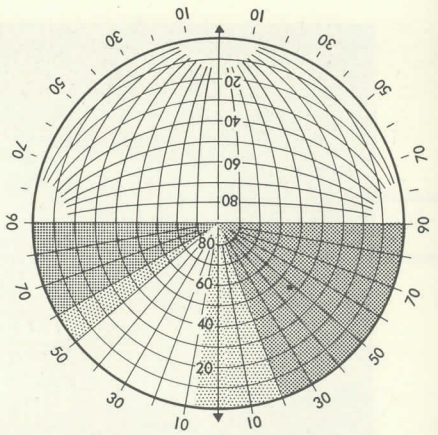








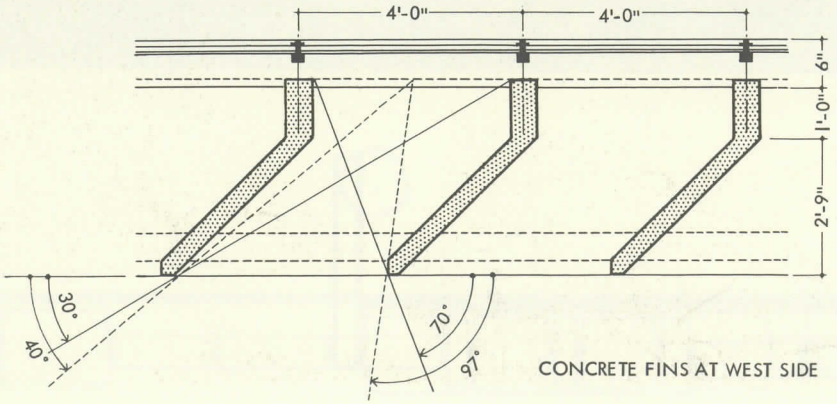




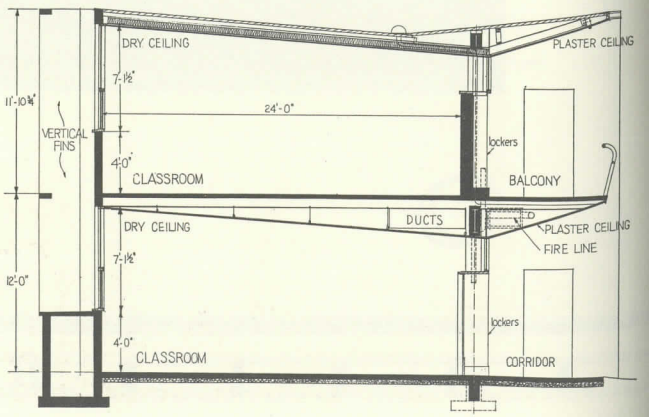
GUIREY & JONES, *School Building, Phoenix, Arizona*

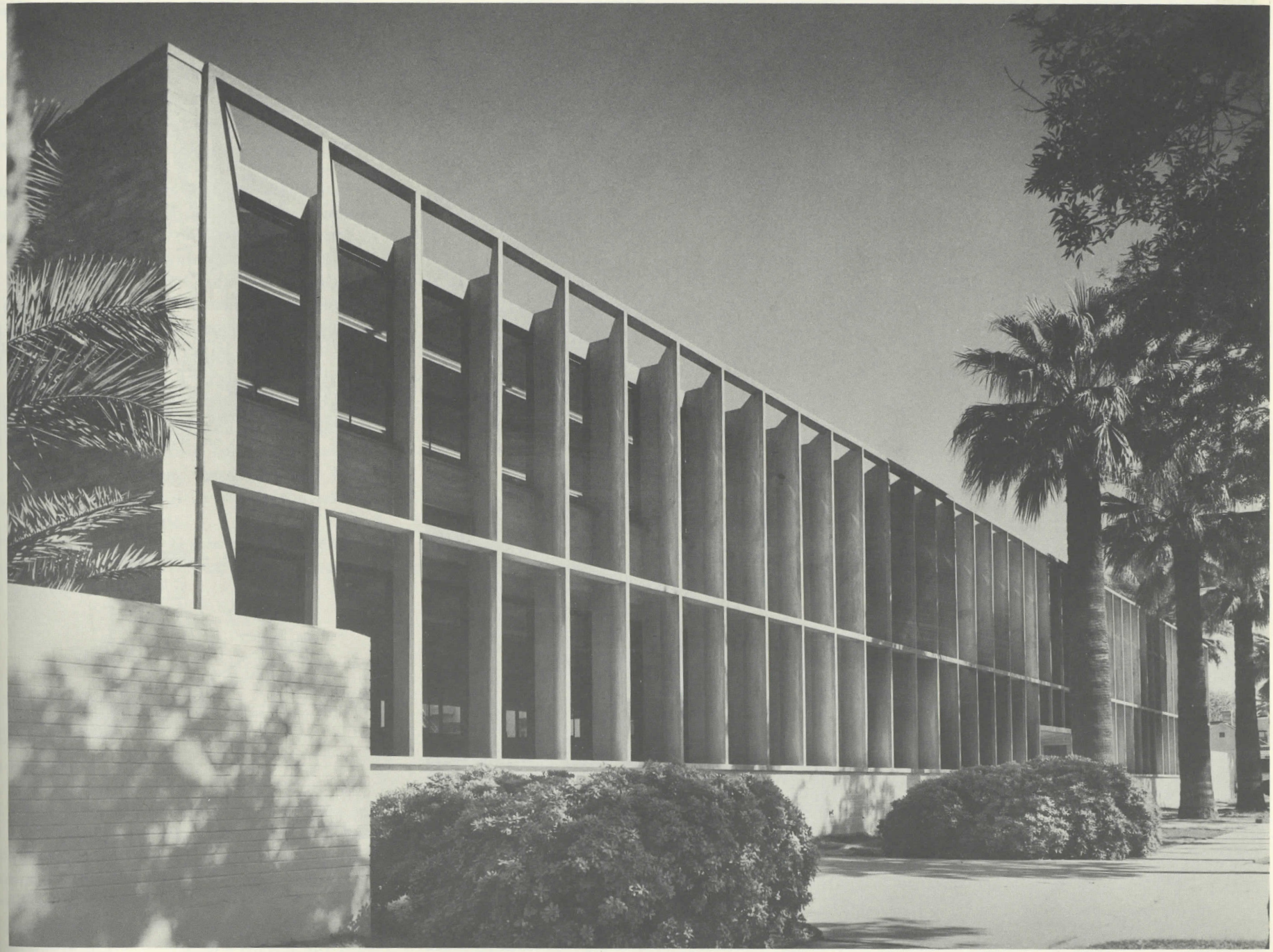
The whole elevation of this school building is covered with vertical concrete fins, as protection against the sun of this region. The fixed concrete fins stand independently in front of the building, thus avoiding heat transmission and securing air movement.

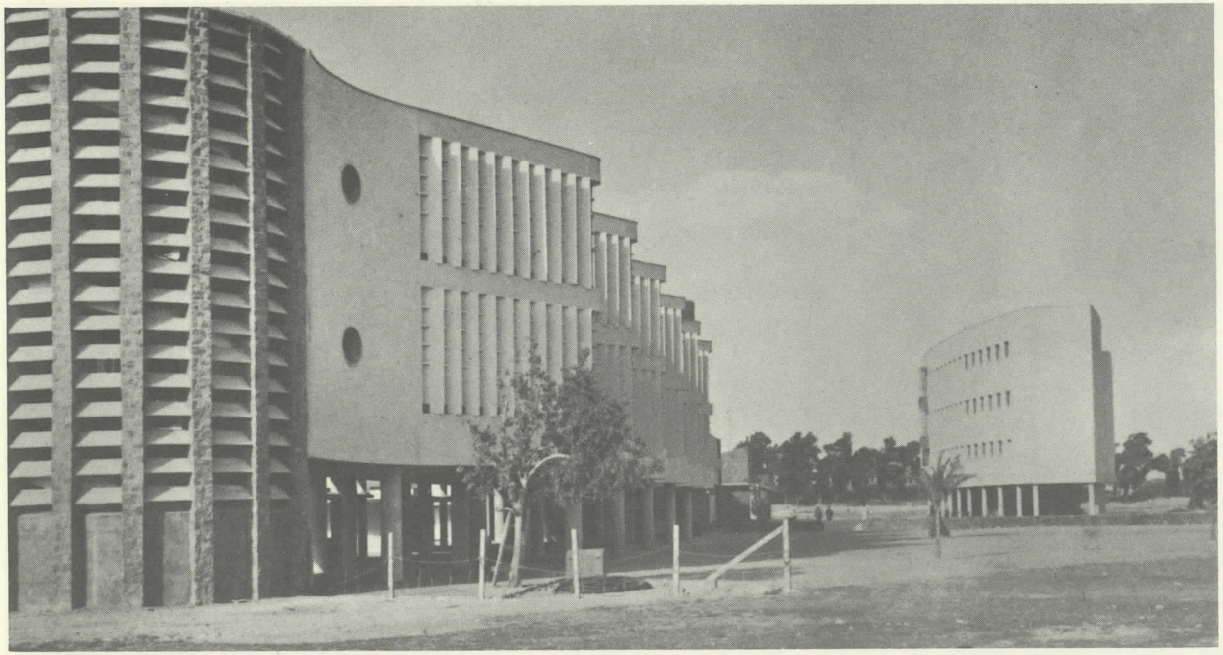
Spaced 4 feet apart and pointing to the northwest, at an angle of 45° to the facade, the fins deflect heat and glare from the street. The architect estimates that substitution of fins for conventional blinds save about $4000 in initial costs and hundreds of dollars in yearly maintenance.

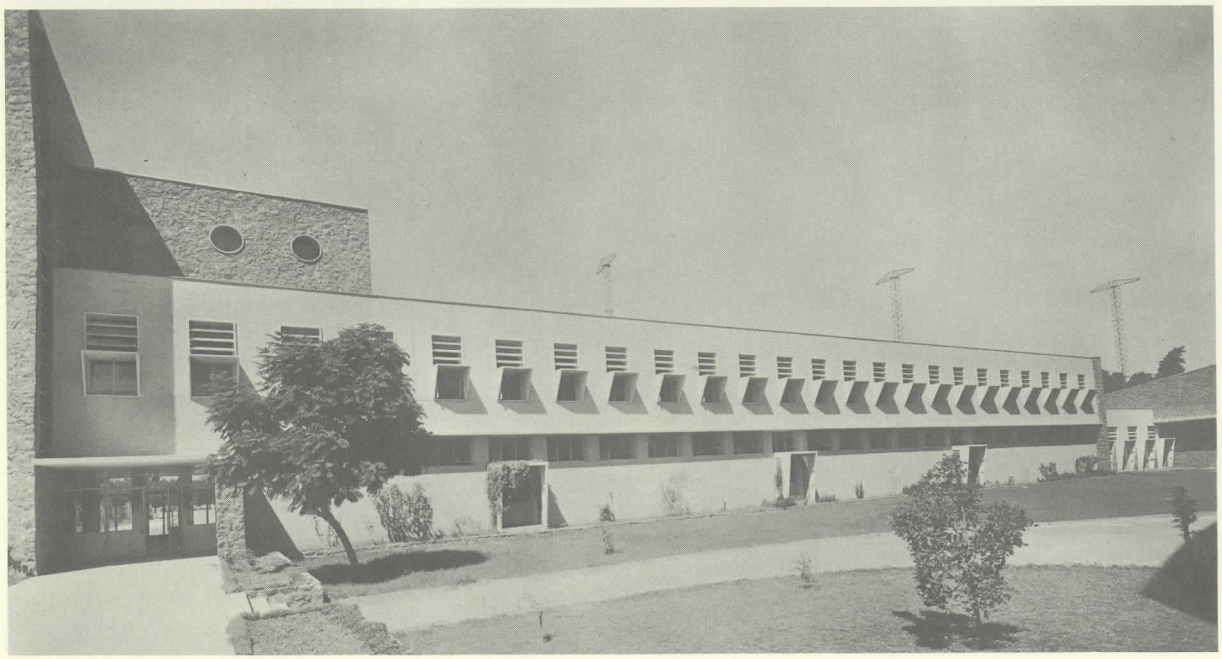


CONCRETE FINS AT WEST SIDE







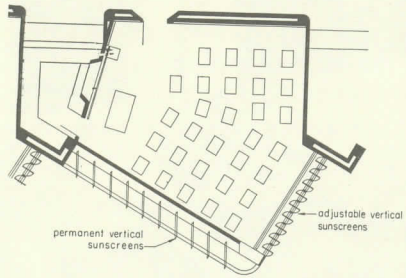


JOHN W. POLTOCK, *Victoria College, Cairo, Egypt*

Egypt's broiling sun made the design of the new campus of Cairo's Victoria College an expression of shading and ventilated spaces. A wide range of louvers and canopies reduce sky glare, screen direct sunlight, and also channel the air movements.

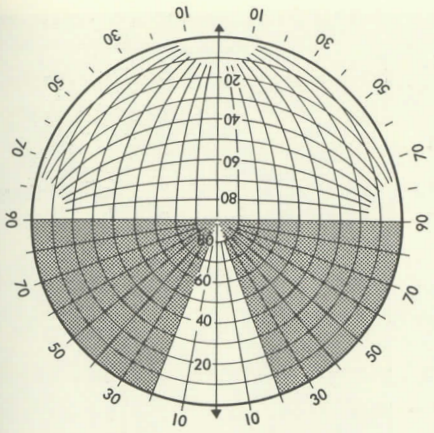
On one elevation of the building, the small window openings have fixed horizontal louvers to control glare and direct air into the rooms. In addition a fixed canopy with side checks reduces sun infiltration.

The main classroom block has two floors of wedge-shaped classrooms set at an angle to the main axis of the building. One exterior wall of each room gets eastern sun. Here, adjustable vertical louvers of hollow insulation-filled metal are ganged together and manually operated to admit solar heat on winter mornings. During



hot months the louvers are closed and the insulated fins help keep out the heat.

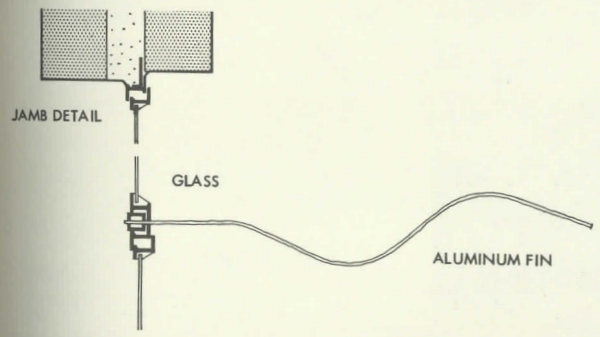
Each classroom also has a south exterior wall. Here, deep, fixed vertical louvers eliminate sky glare when students look toward the blackboards. Louvers also direct incoming light toward the teacher's desk.



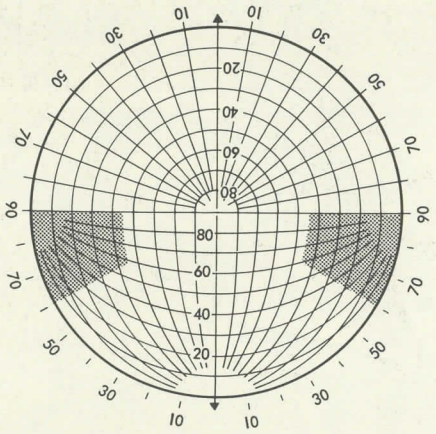
A. LUSTIG & S. REISBORD, *Beverly-Carlton Hotel, Beverly Hills, California*

On the elevation the large living room windows, which run from floor to ceiling, are protected by a system of fixed aluminum fins. These fins are designed in a uniform curve, and are set in the mullions holding the glass. This form of undulating surface gives a rich contrast to the otherwise flat facade.

The shading mask indicates the characteristics of this type in its effectiveness toward a western and eastern elevation.

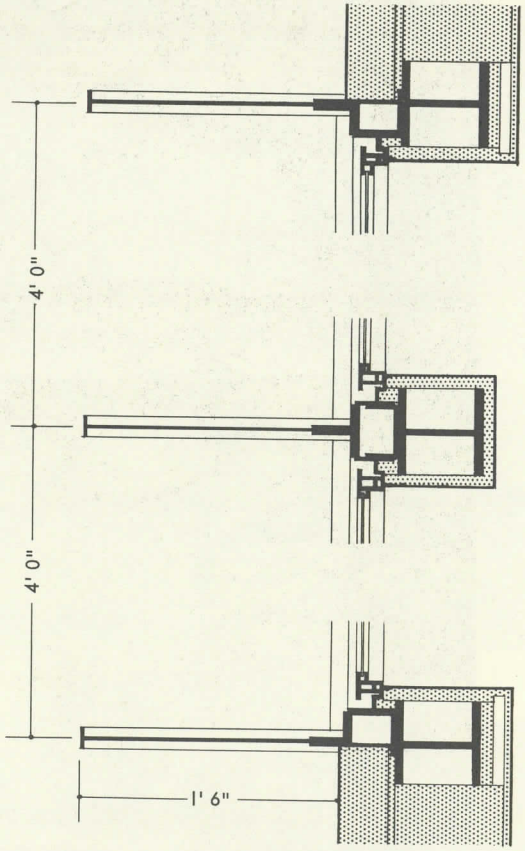


MULLION AND FIN DETAIL

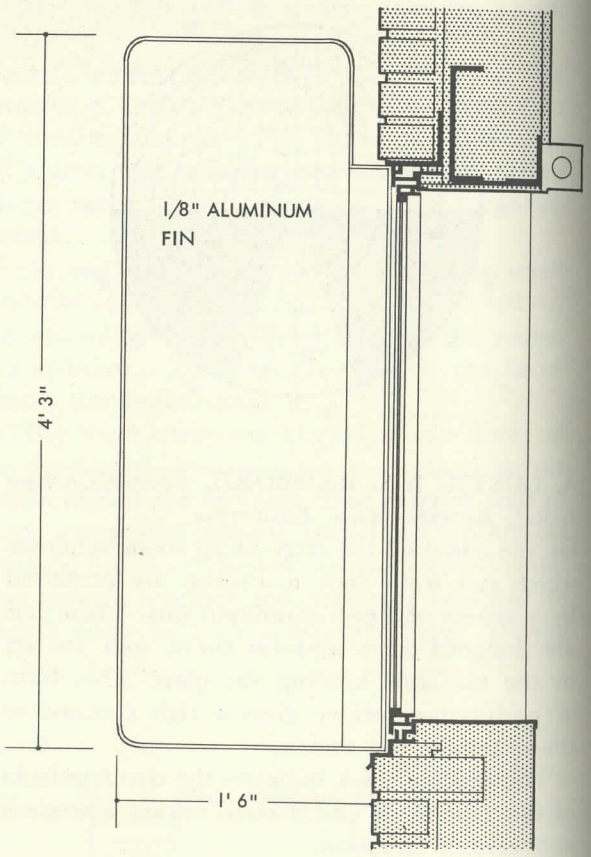


MAGNEY, TUSLER, SETTER, *University of Minnesota, Minneapolis*

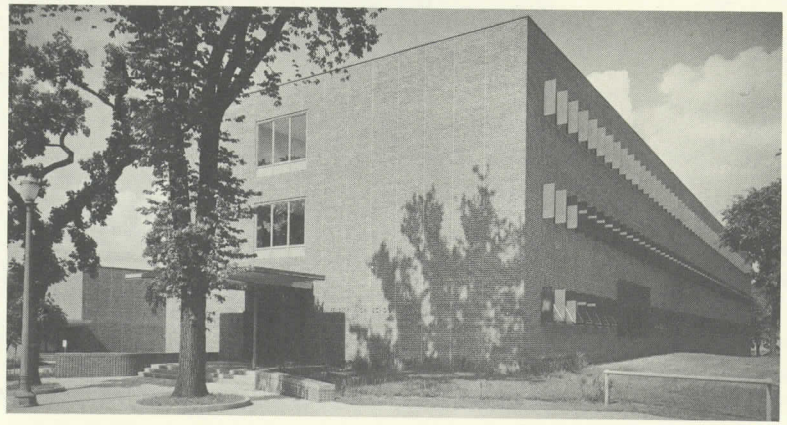
The aluminum fins are fixed on each mullion uniformly throughout the elevation of the building. The effect of the blinder is to avoid glare; however, the lack of horizontal elements results in considerable heat transmission.

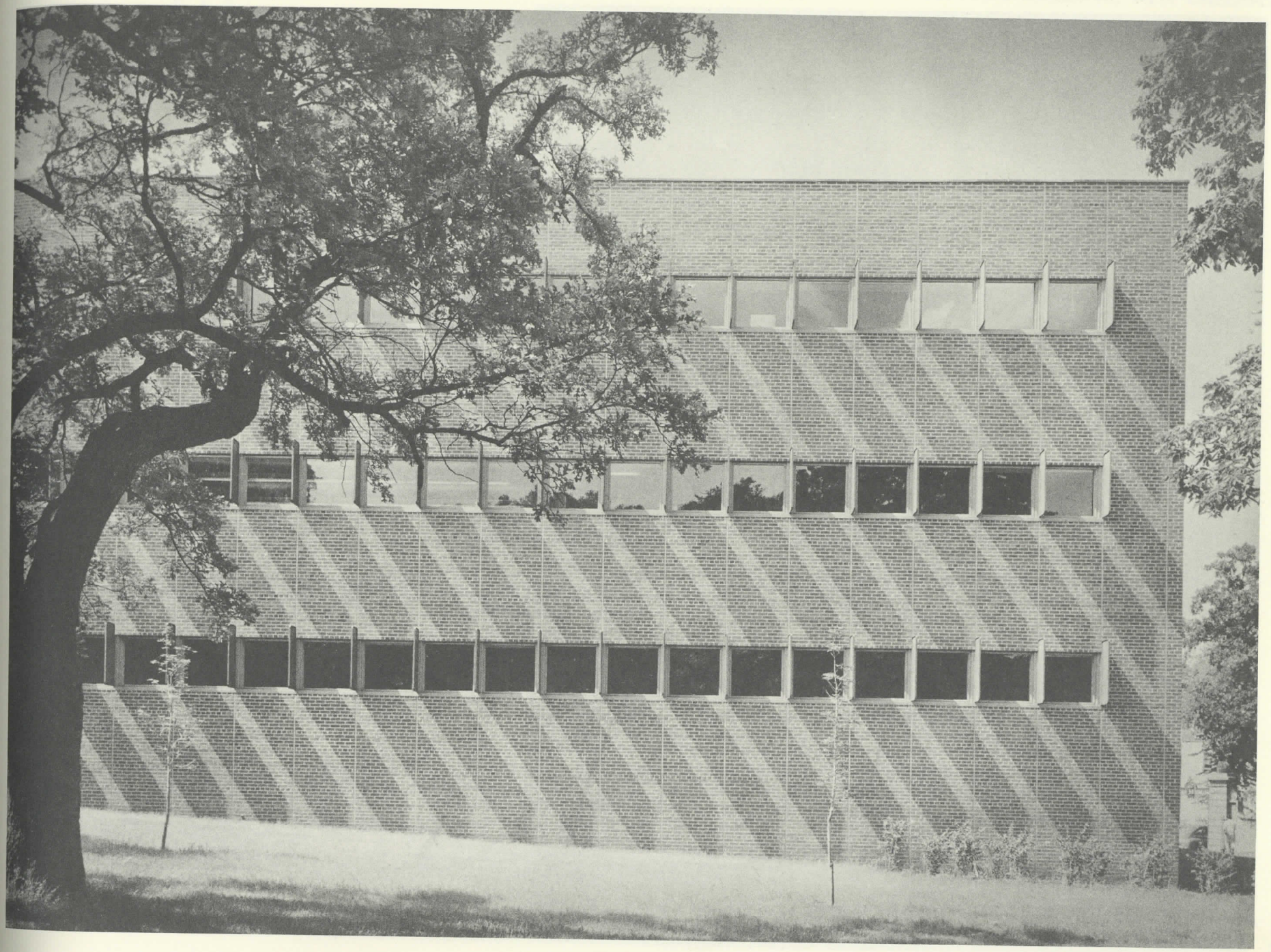


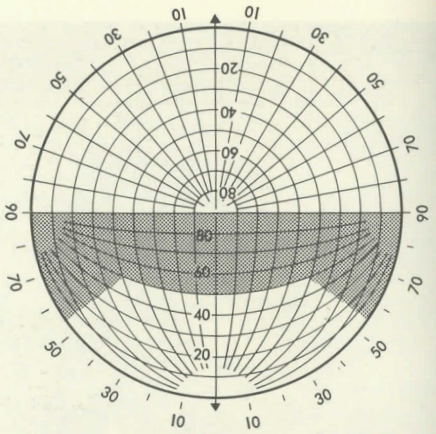
PLAN



SECTION

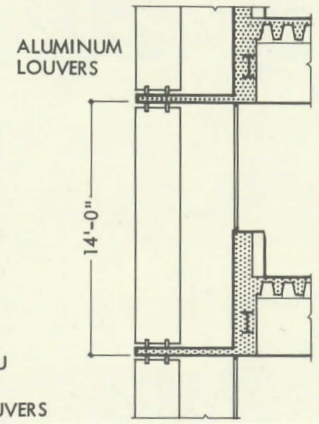




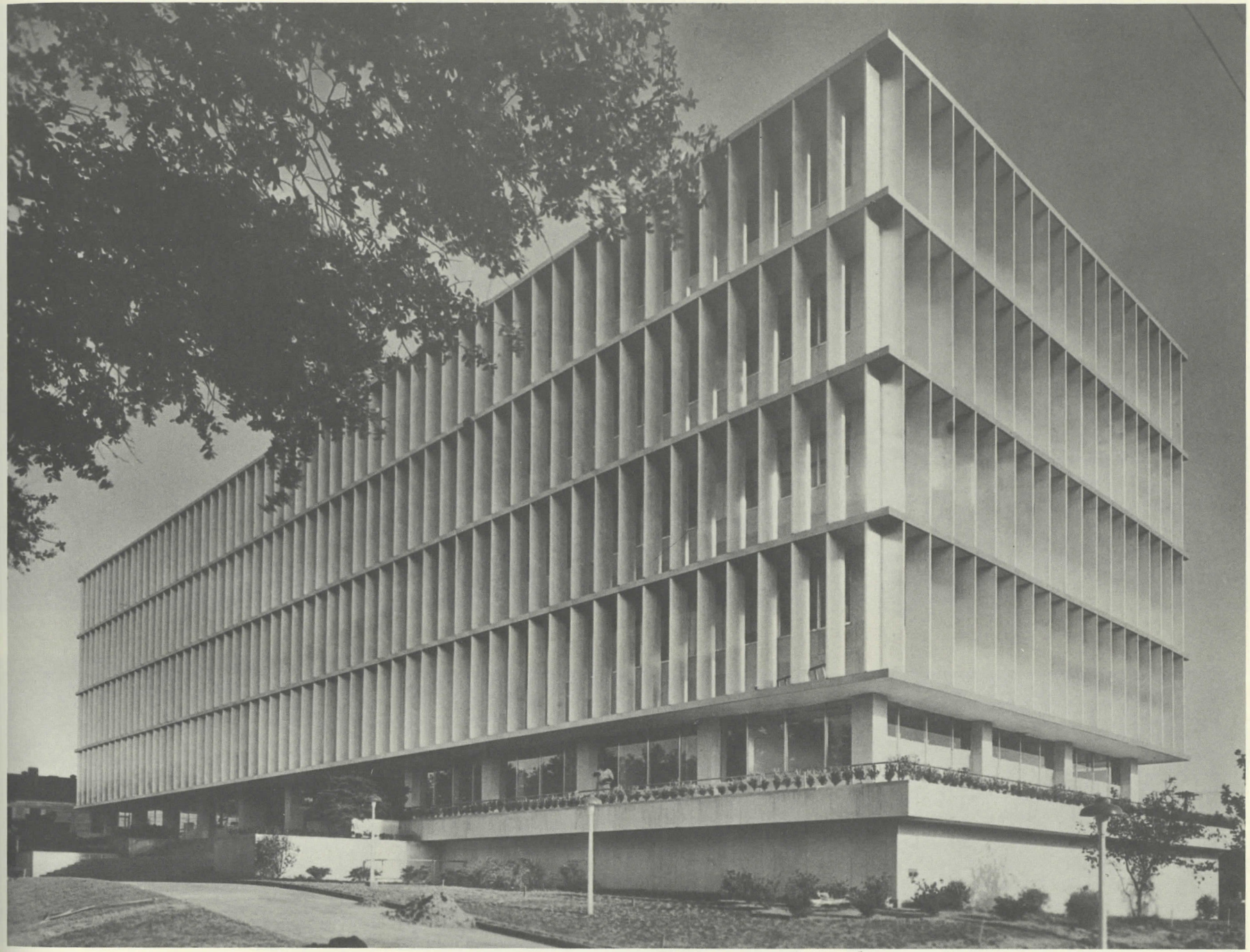


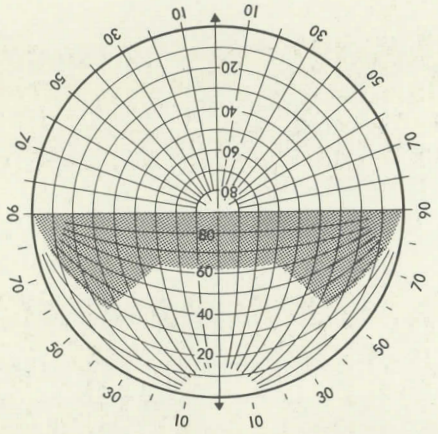
SKIDMORE, OWINGS & MERRILL AND C. E. HOONTON, *Pan American Life Insurance Building, New Orleans, Louisiana*

The main rectangular unit of the building is covered on all four sides with fixed vertical aluminum louvers, which in combination with the extended horizontal concrete slabs result in an eggcrate mask. The use of the same type of device around the building gives an architectural unity, but can not be justified functionally. The same effect could have been achieved with different dimensioning toward the various orientations.

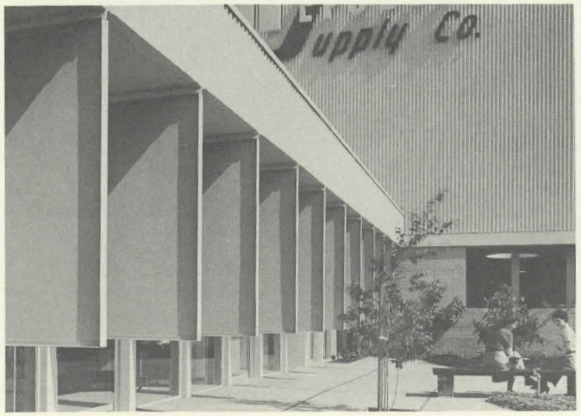


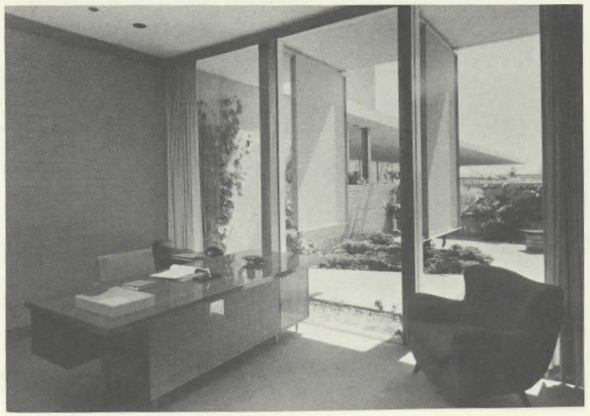
SECTION THRU
VERTICAL LOUVERS

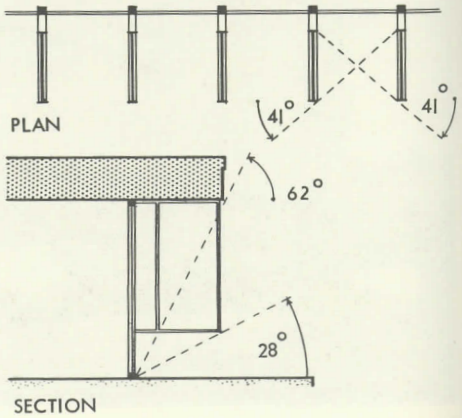


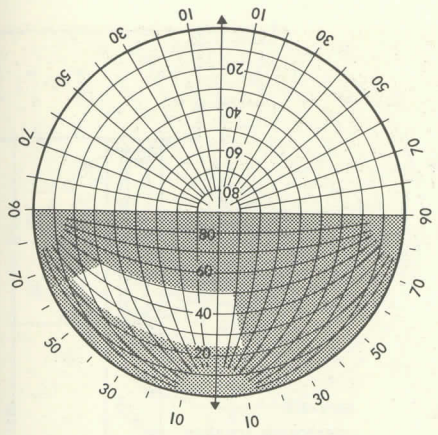


GEORGE VERNON RUSSELL, *Republic Supply Co., San Leandro, California*
A continuous five-foot roof overhang keeps sky glare from entering the office wing, and the sun-fins along the east side of the executive wing solve the early morning sun penetration problem. The sun-control devices are constructed of fixed rectilinear transite panels with a supporting frame of metal angles. The panels are painted a warm grey and the angles are trimmed in yellow.



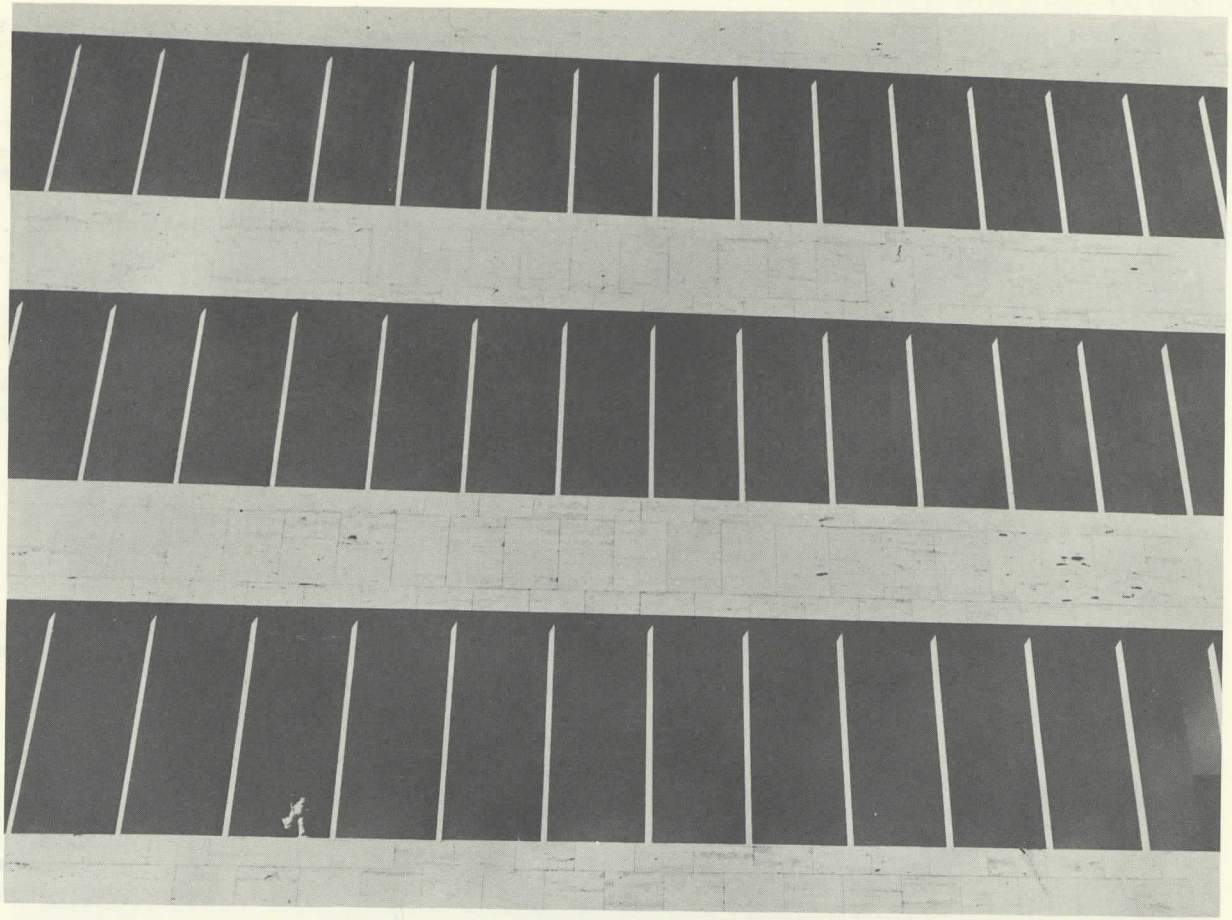


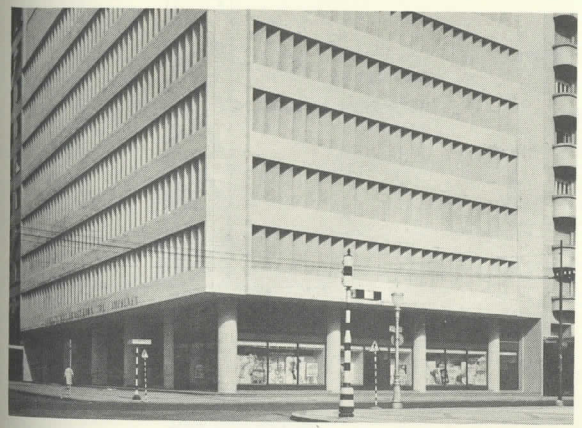


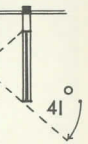


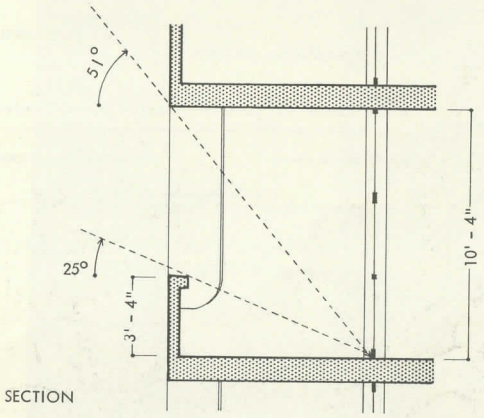
M. M. M. ROBERTO, *A.B.I. Building, Rio de Janeiro, Brazil*

The *brise-soleil* is constructed of diagonally fixed concrete slabs, each 32 inches deep and 2¾ inches thick. A corridor or dispersal zone separates the office opening from the horizontal bands of louver, thus reducing heat and sun penetration. The sun-shades are used on the two facades which have equal exposure to the sun.









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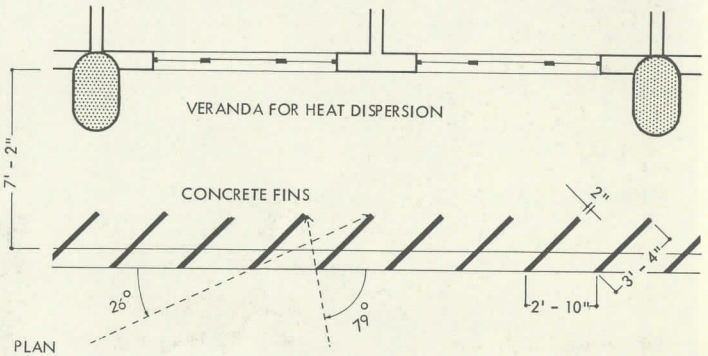
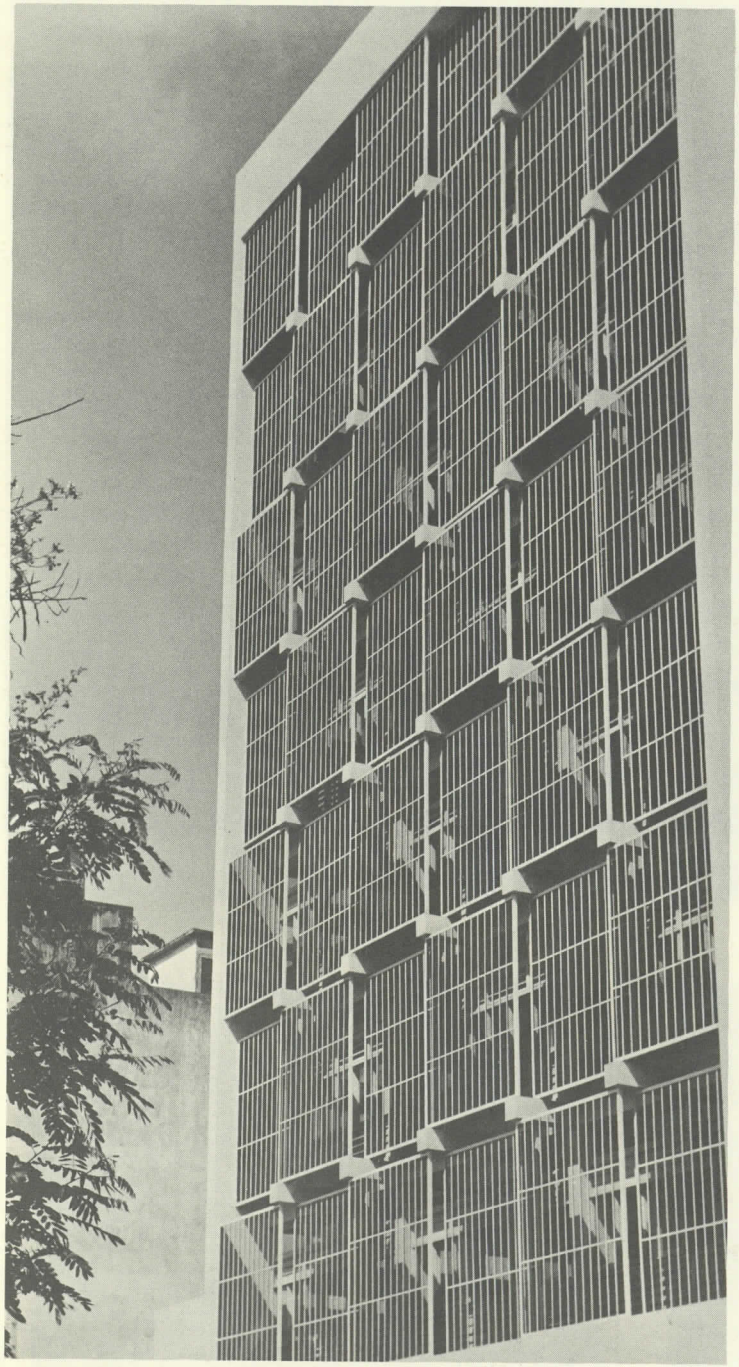
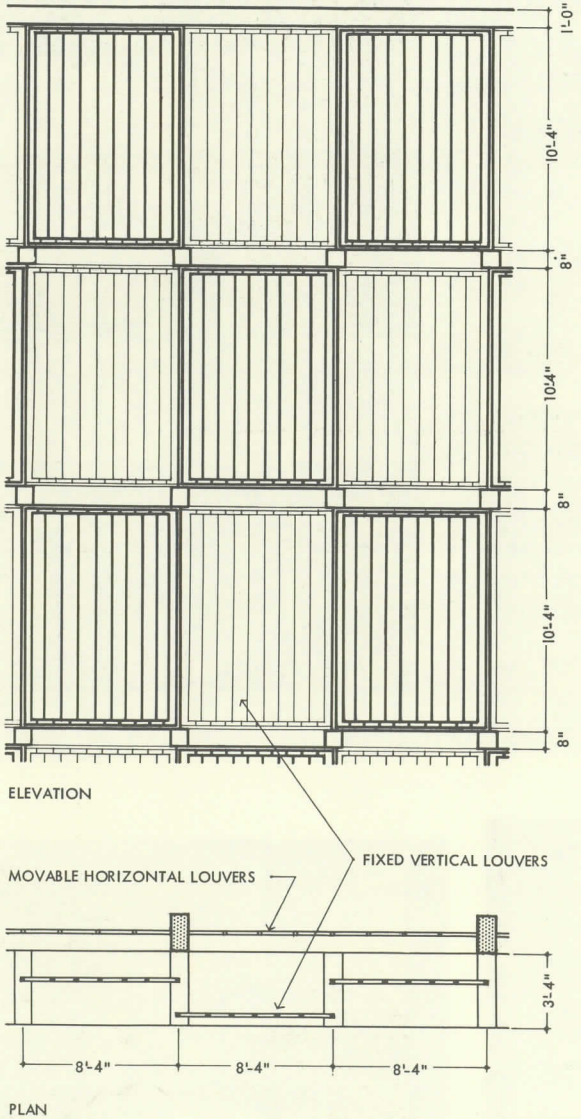
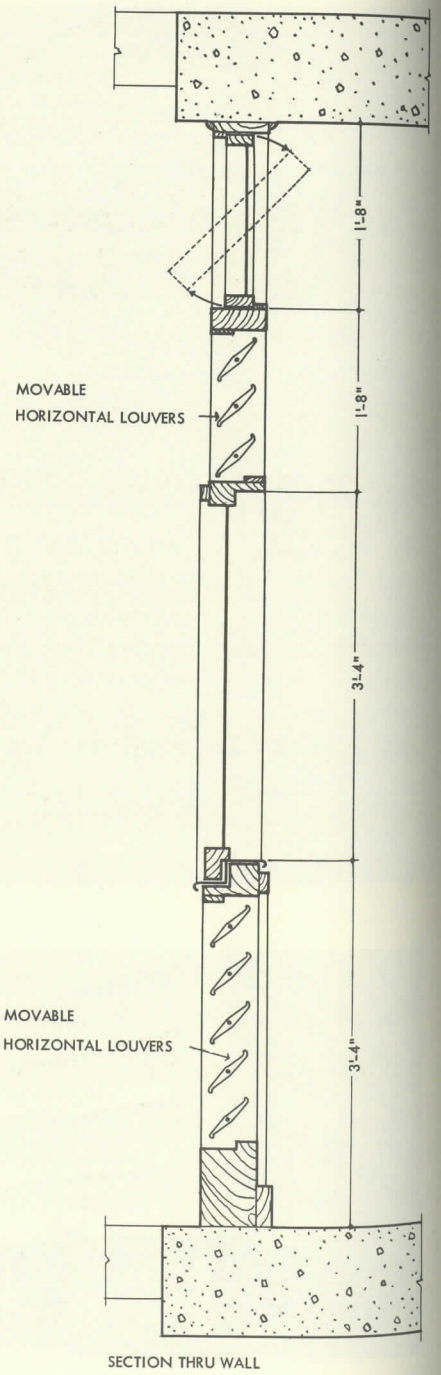
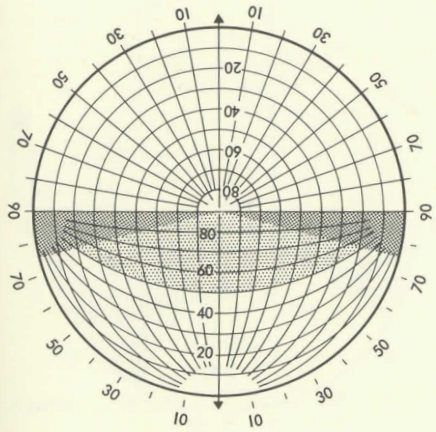


PLAN



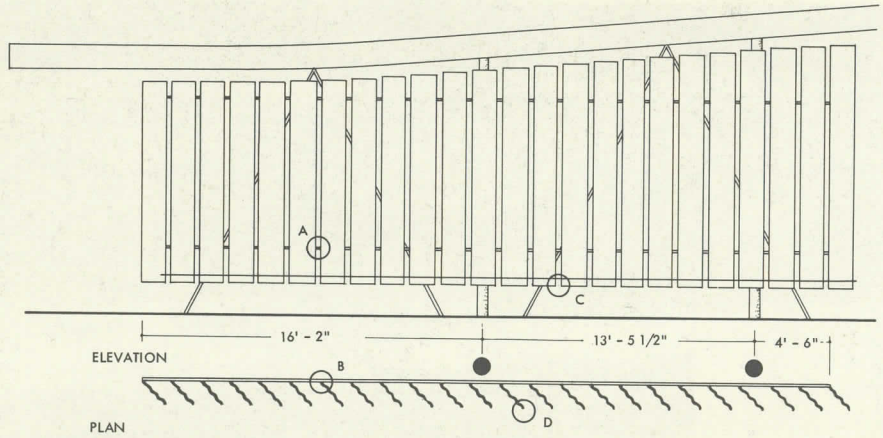

1'-0"
10'-4"
8"
10'-4"
8"
10'-4"
8"
ELEVATION
FIXED VERTICAL LOUVERS
MOVABLE HORIZONTAL LOUVERS
3'-4"
8'-4"
8'-4"
8'-4"
PLAN

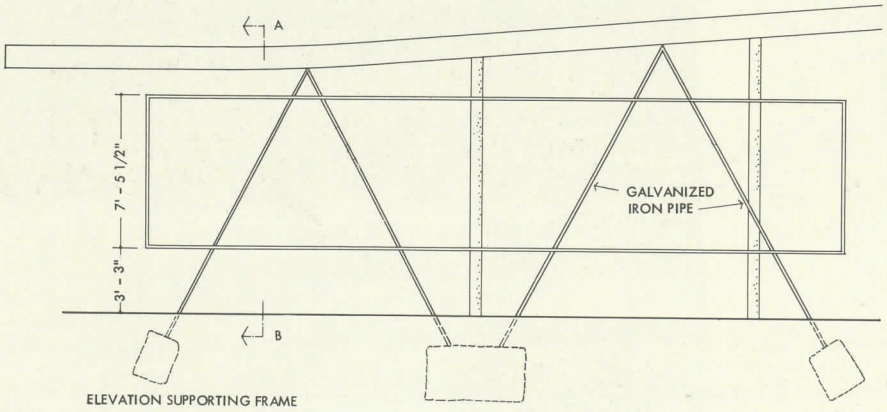

1'-8"
MOVABLE
HORIZONTAL LOUVERS
1'-8"
3'-4"
MOVABLE
HORIZONTAL LOUVERS
3'-4"
SECTION THRU WALL

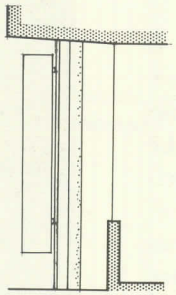


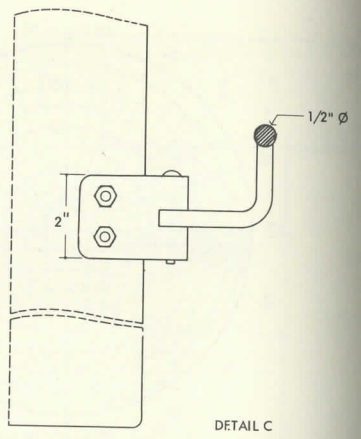
PAULO ANTUNES RIBERO, *Office Building, Bahia, Brazil*

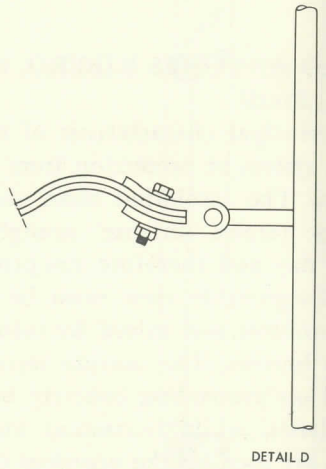
The principal characteristic of this building is in the system of protection from the sun's penetration. The insolation chart showed that two facades receive intense sunlight during the whole day and therefore sun-protection as well as a disagreeable view must be taken care of. The problem was solved by using many stories of sun louvers. The outside vertical louvers are placed on protruding concrete beams on different planes, while horizontal movable wooden blinds are used on the openings of the building.

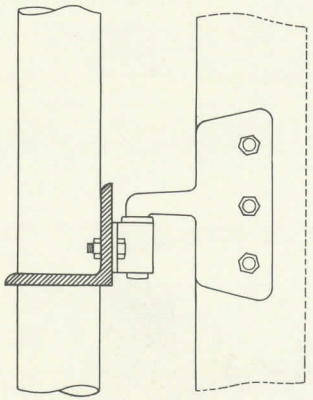


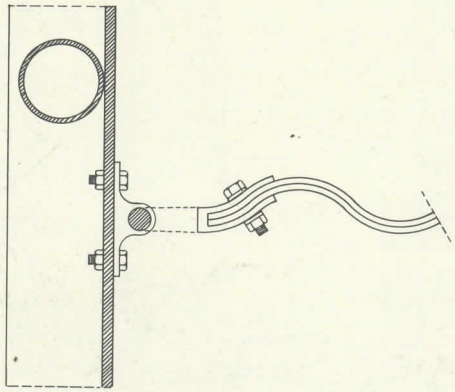




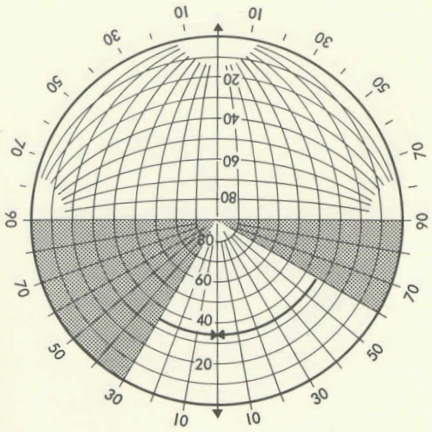




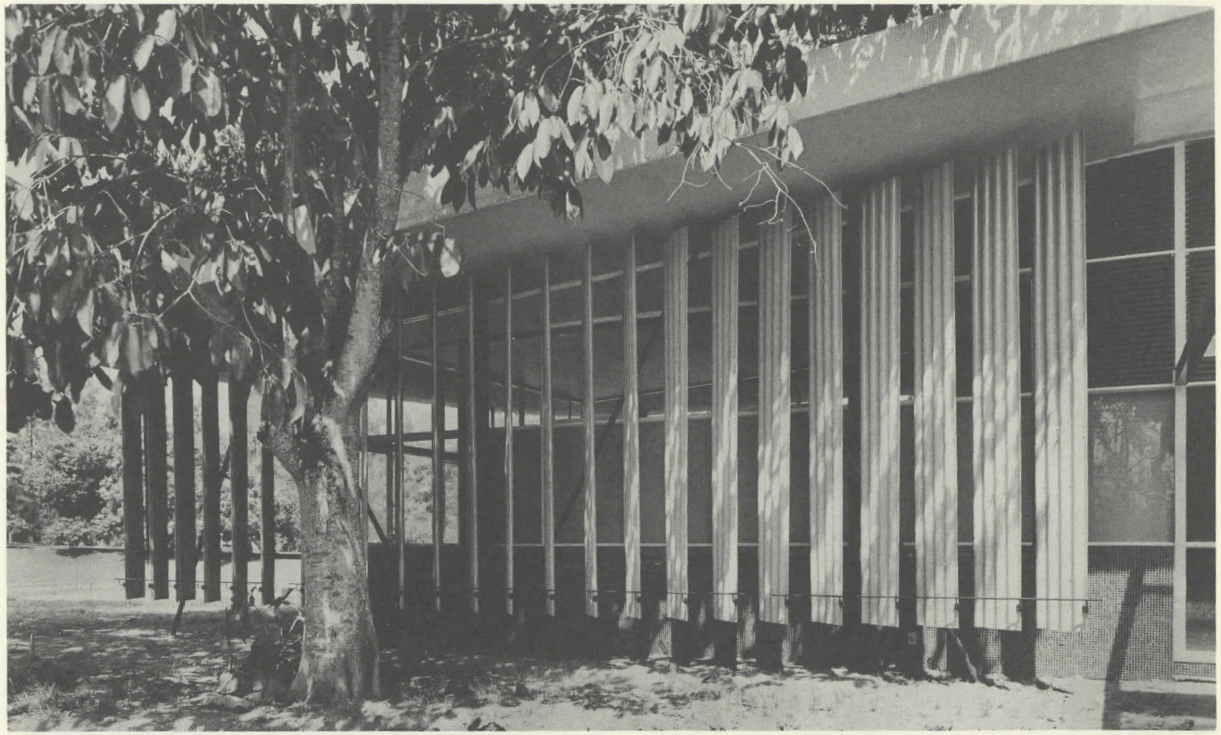


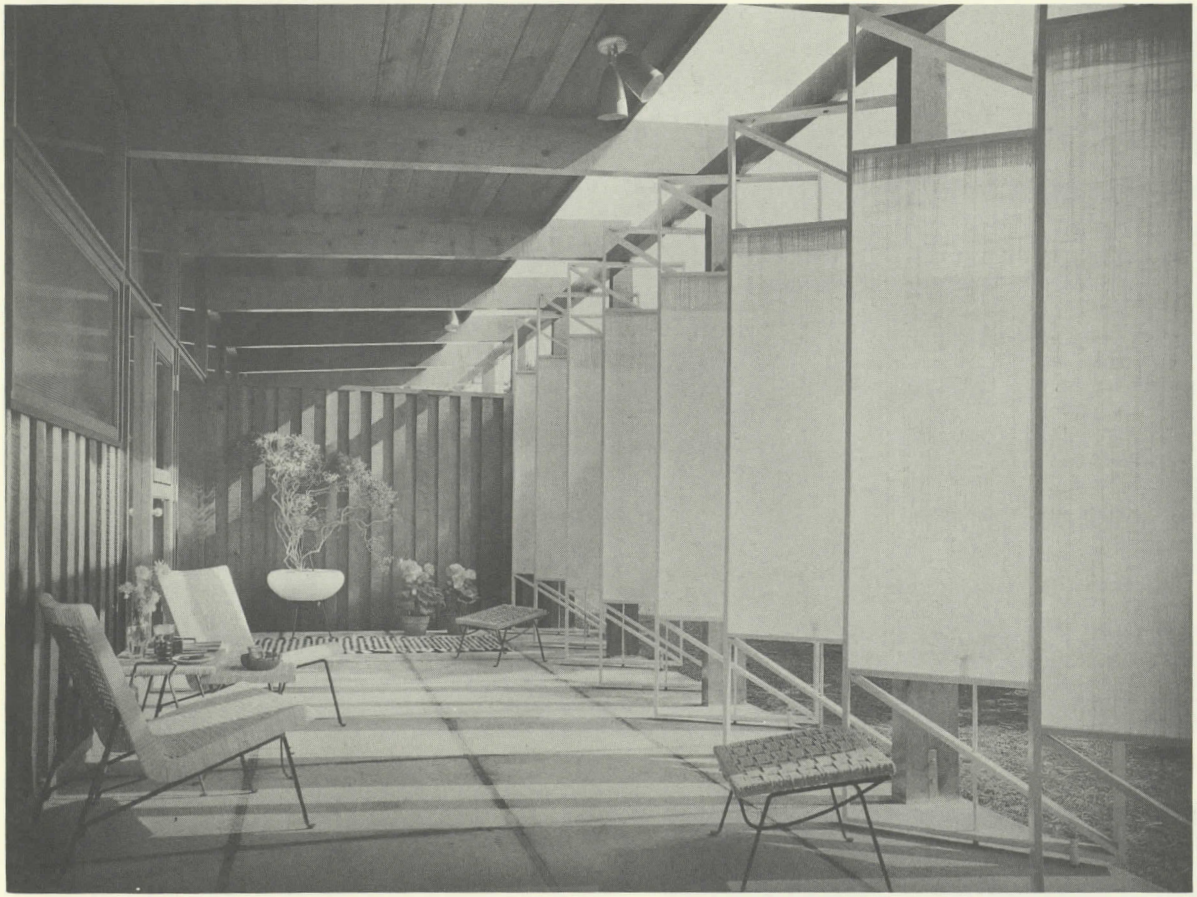


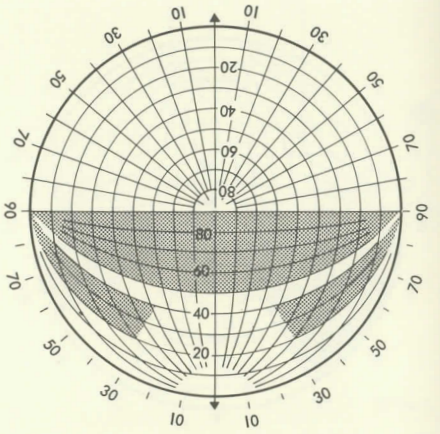
M. M. M. ROBERTO, *Residence of Mr. and Mrs. Arthur Coimbra, Rio de Janeiro, Brazil*
This family house in Rio de Janeiro uses glass surfaces liberally to achieve a close relationship with nature. These openings are protected from the sun with various means: blinds, wide overhangs in different depth according to orientations, and a free standing group of vertical louvers; the last is shown here.

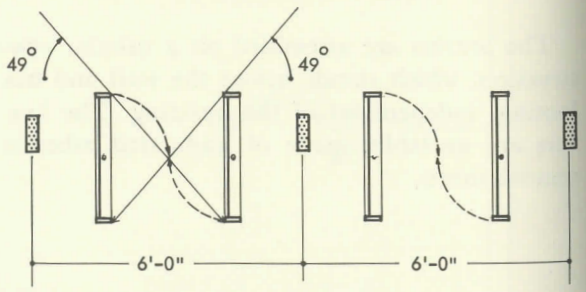


The louvers are assembled on a tubular construction, which stands before the wall and has footings independent of the building. The louvers are movable, made of undulated asbestos cement sheets.

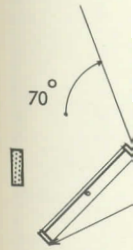








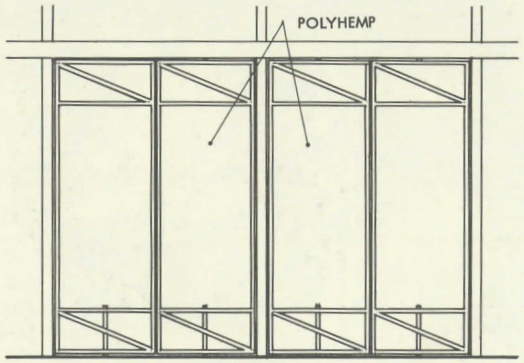
LOUVRES OPEN



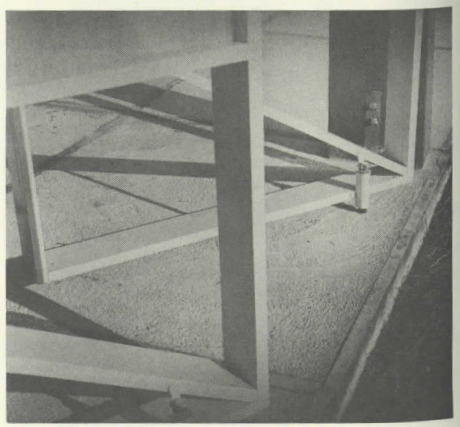
LOUVRES PAR

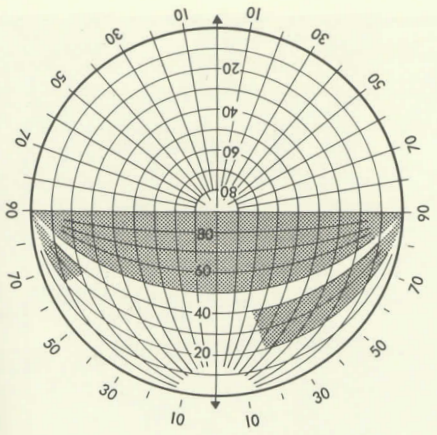
ANSHEN & ALLEN, *House at Yankee Point, Carmel, California*

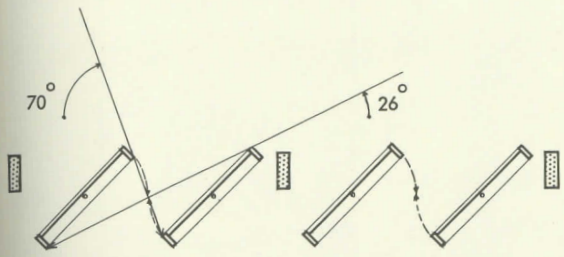
A system of translucent pivoted screens, attached to the outer edge of an eight-foot overhang. These pivoted verticals are operated individually, and can be stopped in any desired position. Thus when the view is pleasant visually and thermally, the blinds are open, as during the early morning periods.



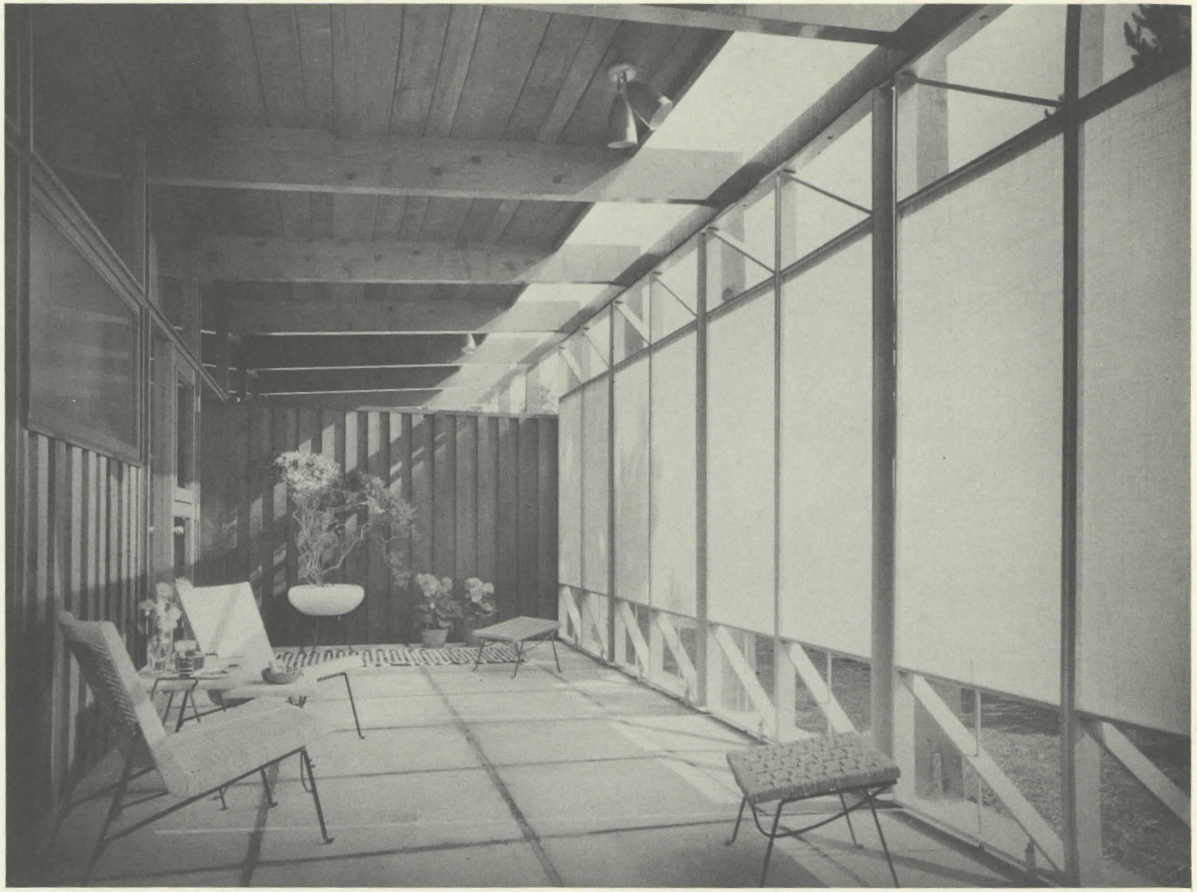
ELEVATION

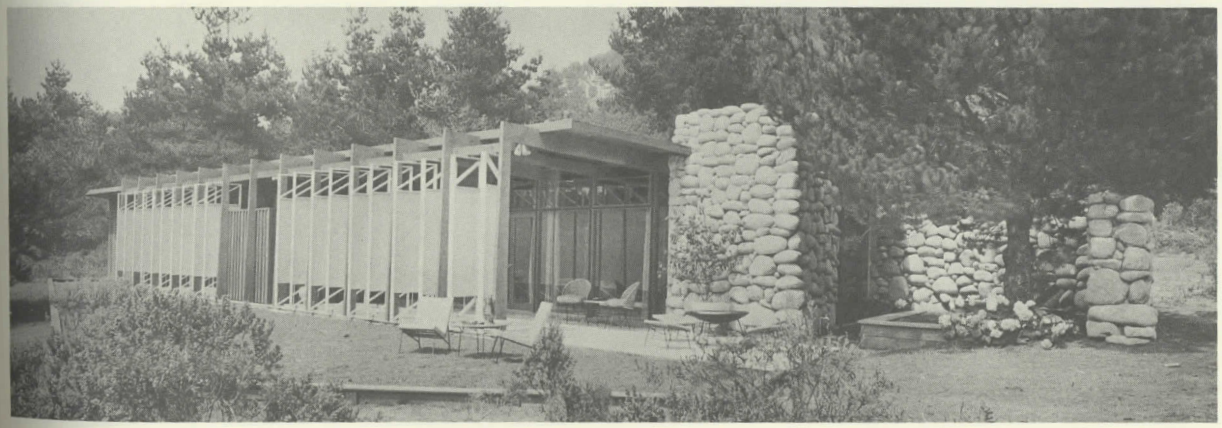




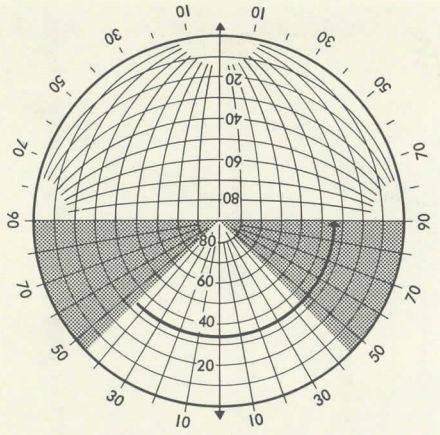


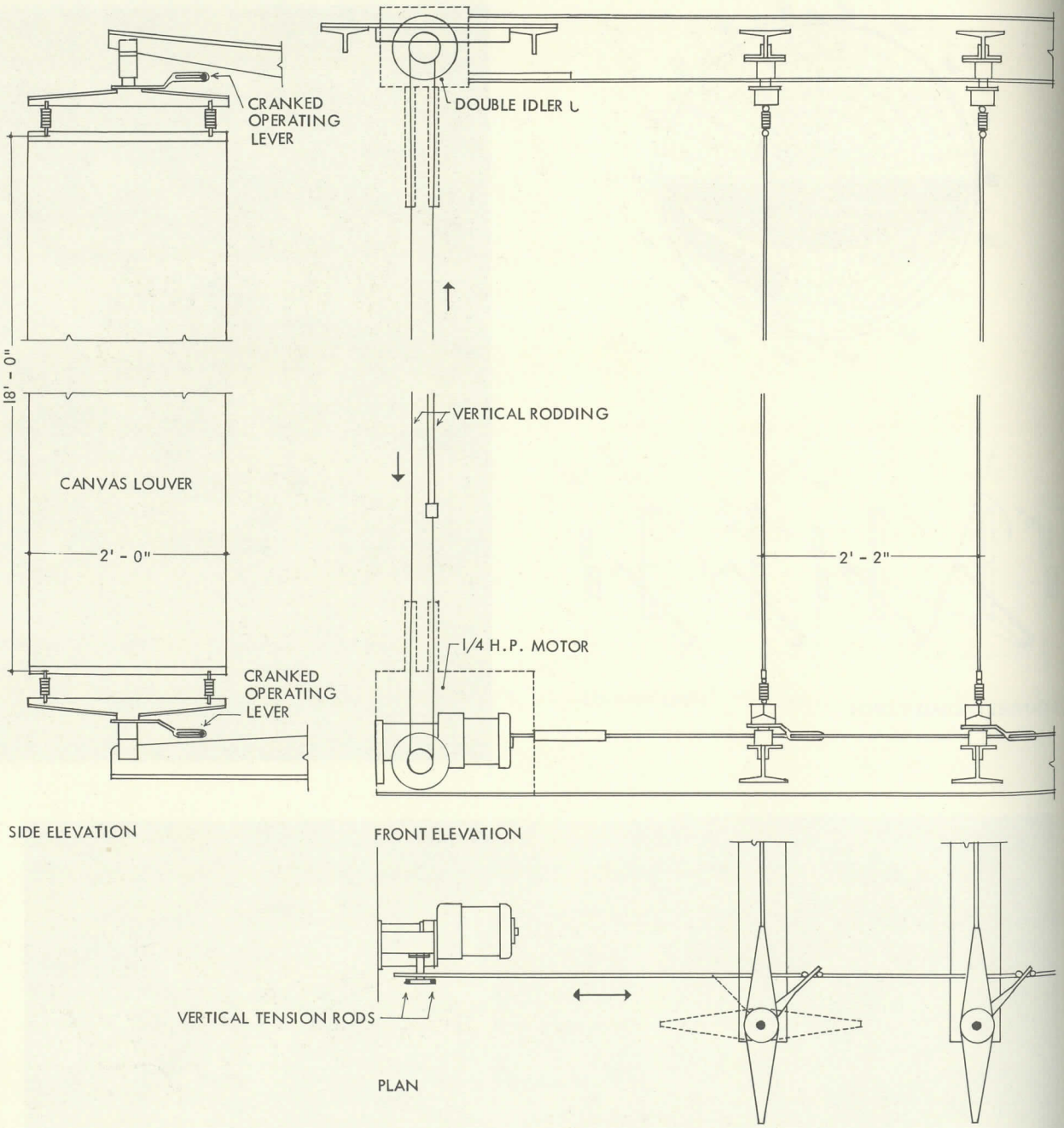
LOUVRES PARTIALLY OPEN





As the sun lowers into the west, the blinds are closed, admitting light and air, but not heat and glare into this terrace area. The vertical screens are composed of rigid weatherproof, fire resistant, laminated polyhemp.

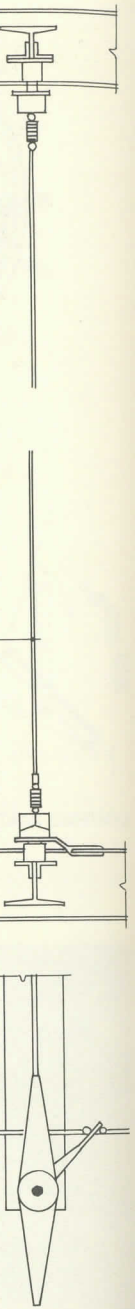


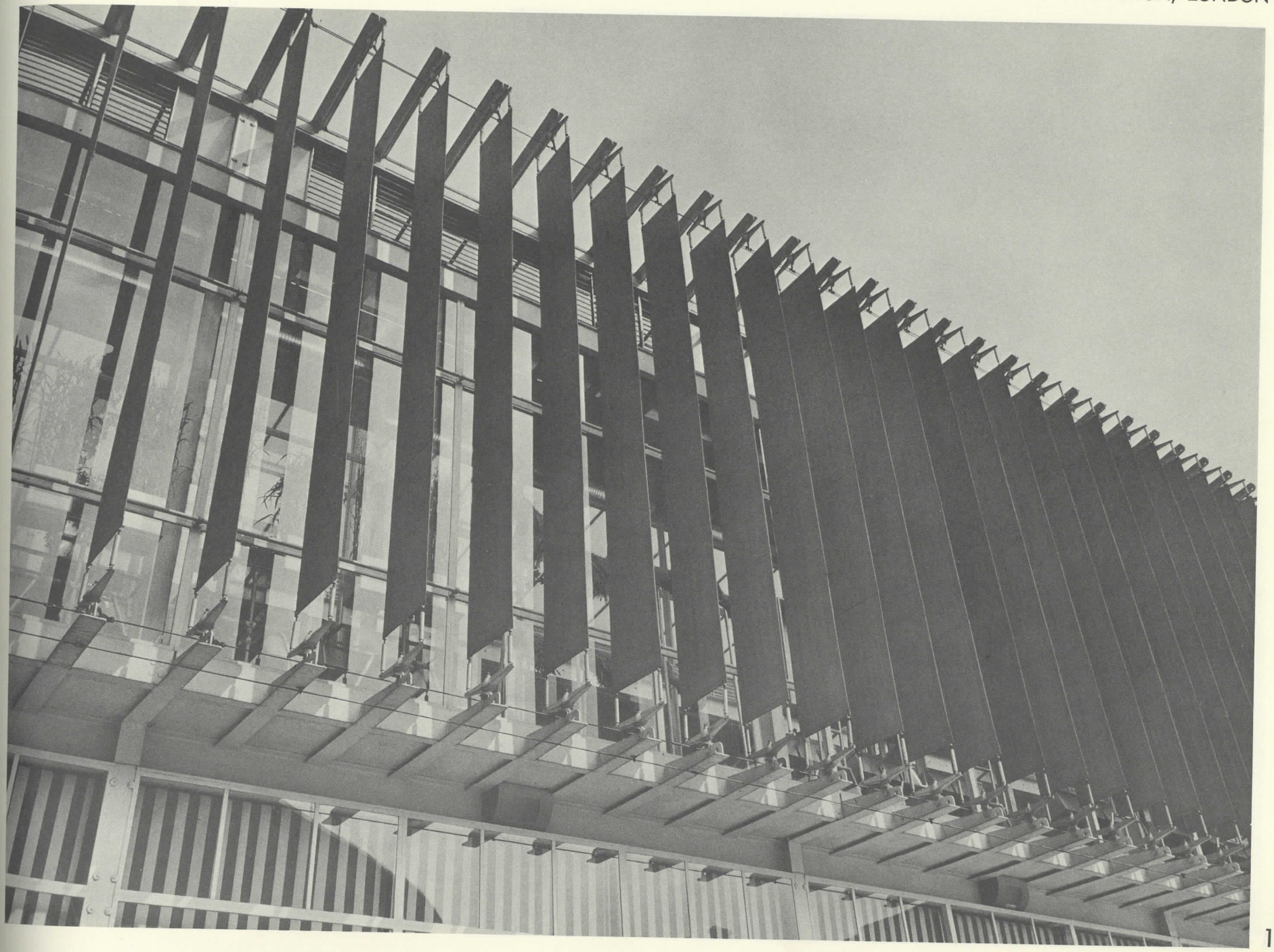


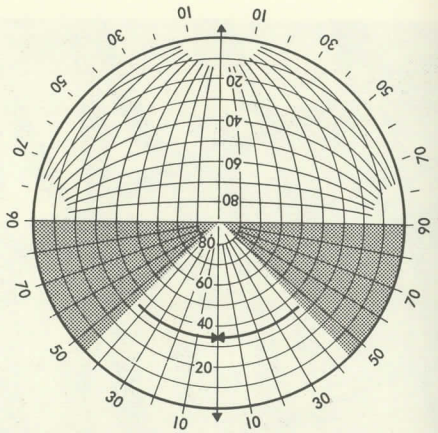
BRIAN O'RORKE, *Festival of Britain, Country Pavilion, London, England*

This screened elevation was designed to shield a section of the agricultural pavilion at the South Bank Exhibition of 1951. In the pavilion there were displays of produce, growing plants, vegetables and flowers, which were changed periodically. As there was no general air-conditioning in the pavilion, which was semi-open air, it was necessary to shield the exhibits from any strong sun striking the glass in the afternoons. The screens were constructed of green canvas panels connected and stretched in spring tension to metal arms. The panels were ganged together and rotated by electrically driven motors.

In order to prevent the canvas from flapping in the wind the crosspieces, to which the canvas was fixed top and bottom, were attached to a second arm by means of spring tension springs. Little flapping was noticed in the arrangement.

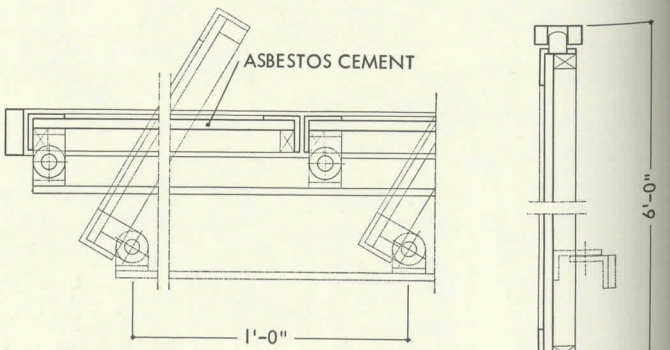




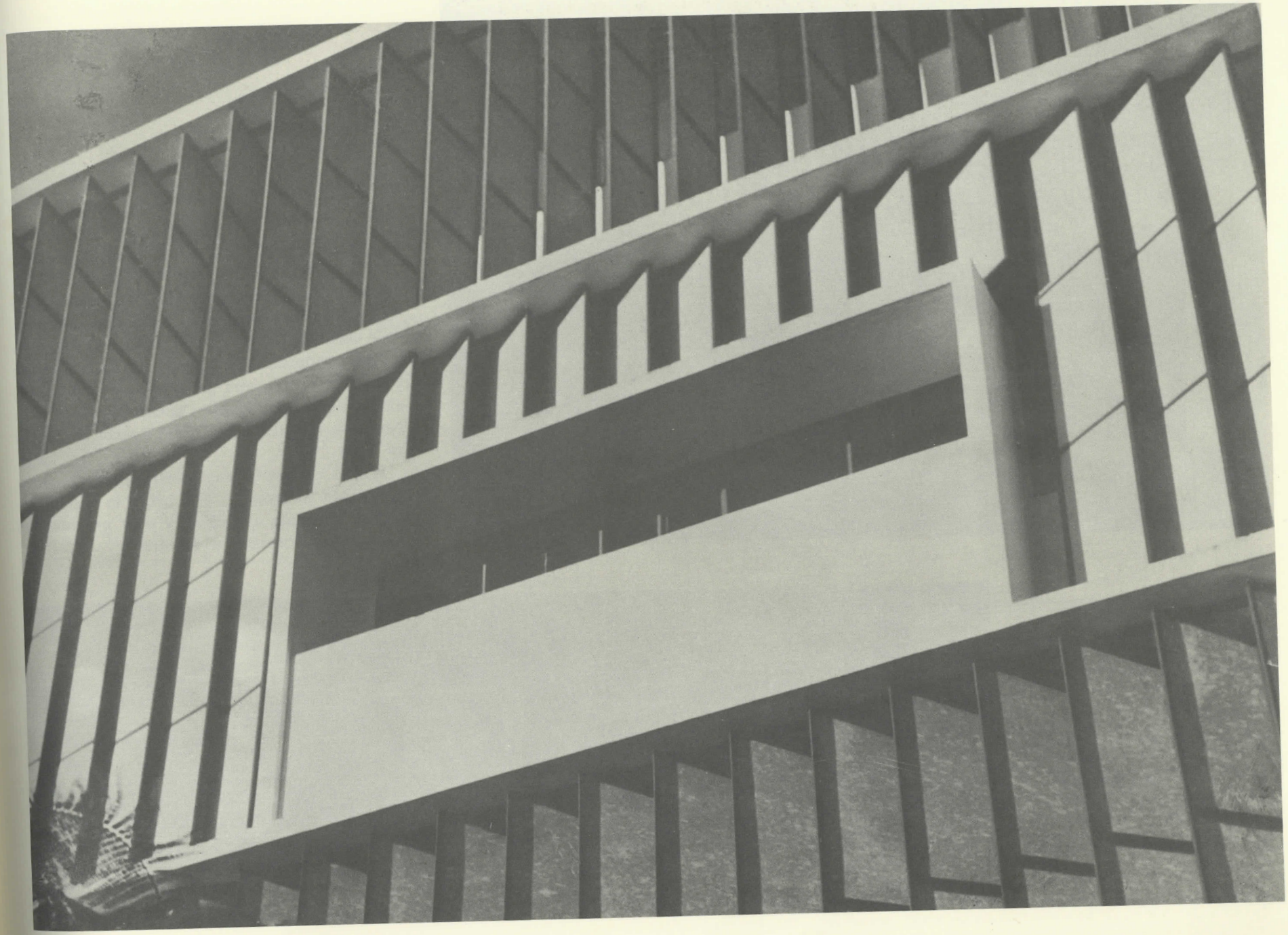


OSCAR NIEMEYER, *Day Nursery, Rio de Janeiro, Brazil*

This day nursery is one of the earliest architectural works of Oscar Niemeyer. Its main element is a cubelike unit on stilts. The western exposure has light modulators consisting of three tiers of vertical adjustable louvers, the only animation on an otherwise static facade. The details of the sunshade consists of vertical sheets of asbestos cement. Roughly six feet by one foot, they are pivoted on metal frames and adjusted from the inside to allow a desirable amount of sun control.



SECTIONS: HORIZONTAL VERTICAL



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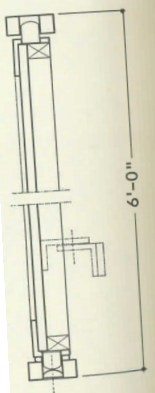
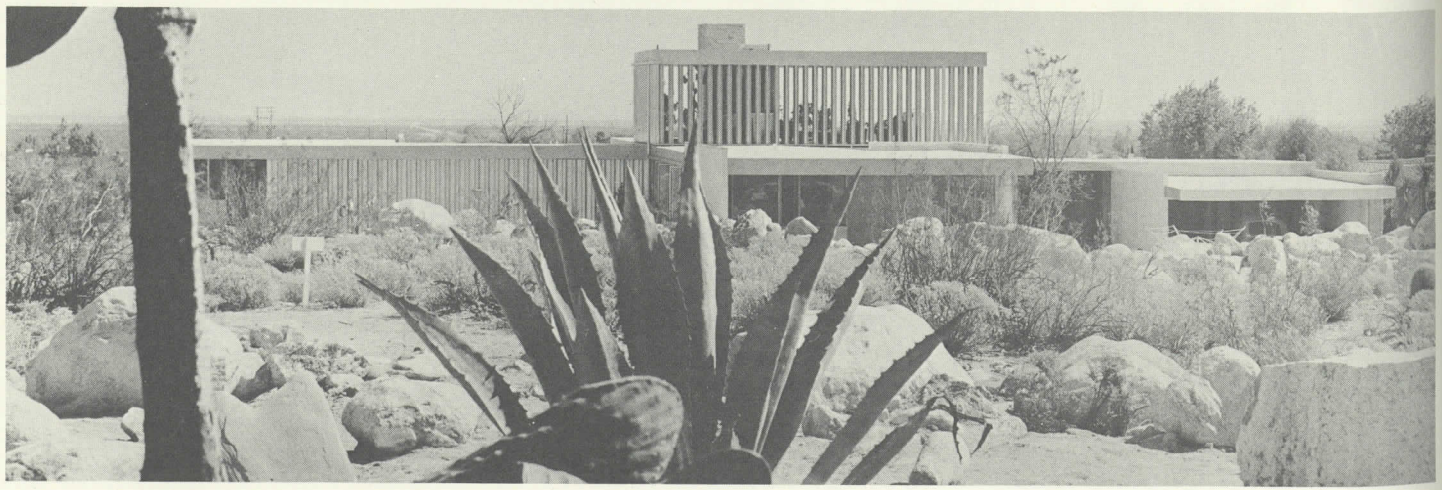
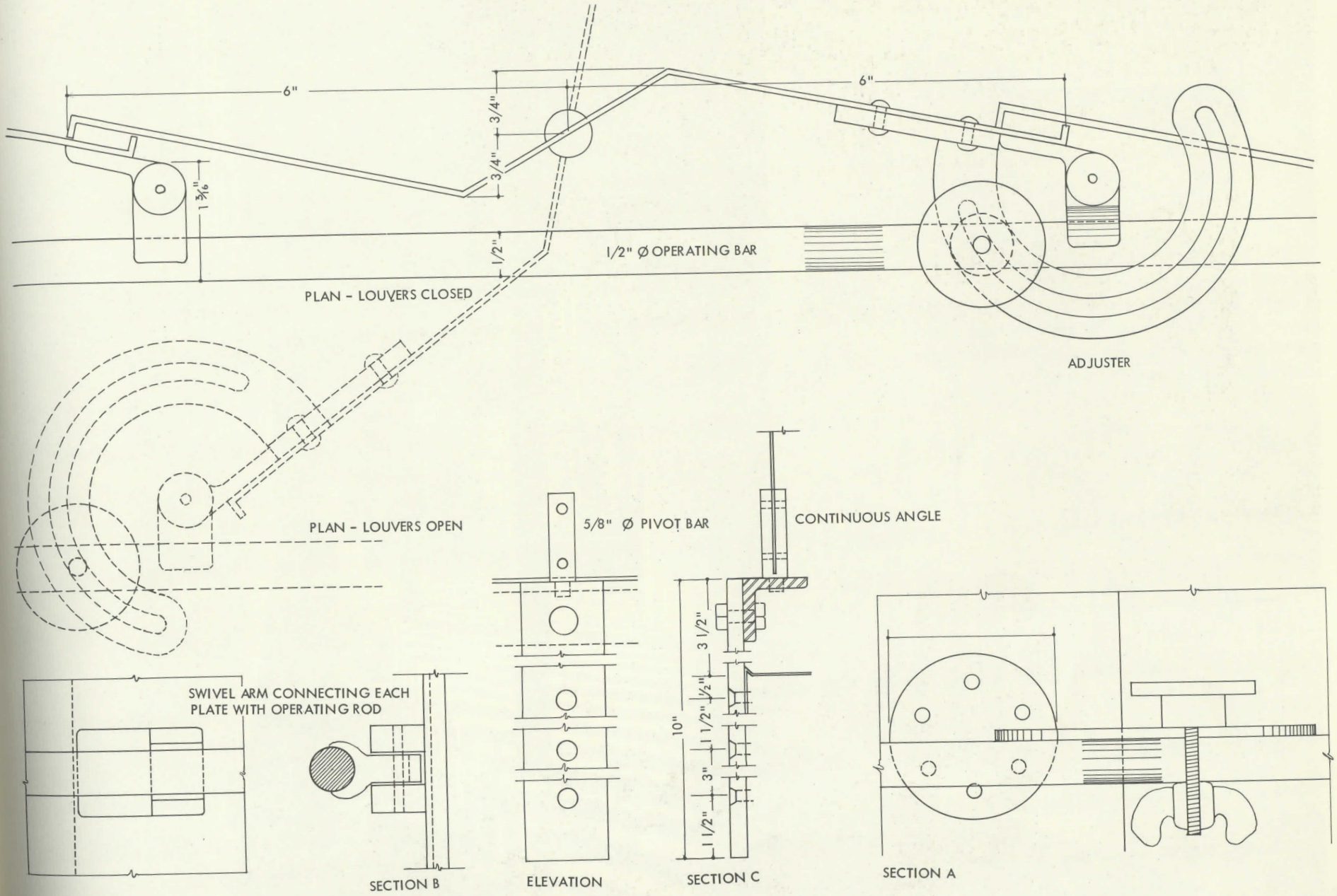


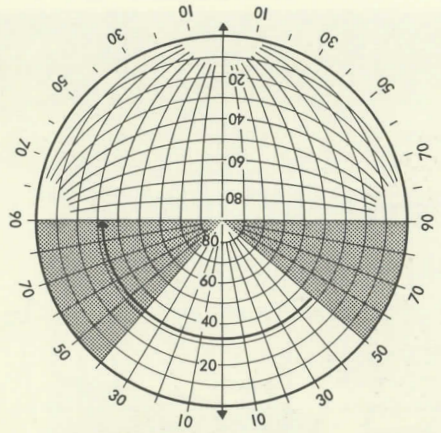
VERTICAL

RICHARD NEUTRA, *Desert House for Edgar J. Kaufman, Palm Springs, California*
In this arid desert surrounding, a shaded shelter was created by horizontal overhangs and movable vertical fins, which determine the character of this residence. The pivoted louver blades are placed 12′ 0″ o.c. and are made up of 14-gauge aluminum. A manually operated adjustment bar allows varied amounts of breeze and light to enter.

Details of the pivoted vertical louvers show adjustable mechanism. The break in the louver surface increases the rigidity and provides an interesting architectural texture.

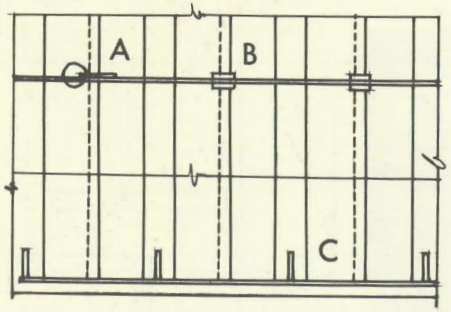


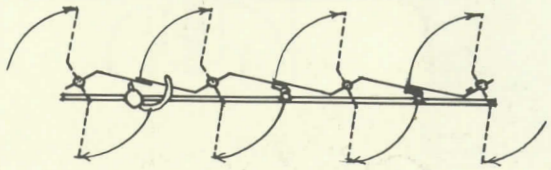

6"
6"
3/4"
3/4"
1 3/16"
1/2"
1/2" Ø OPERATING BAR
PLAN - LOUVERS CLOSED
ADJUSTER
PLAN - LOUVERS OPEN
5/8" Ø PIVOT BAR
CONTINUOUS ANGLE
SWIVEL ARM CONNECTING EACH PLATE WITH OPERATING ROD
SECTION B
ELEVATION
10"
3 1/2"
1/2"
1 1/2"
3"
1 1/2"
SECTION C
SECTION A

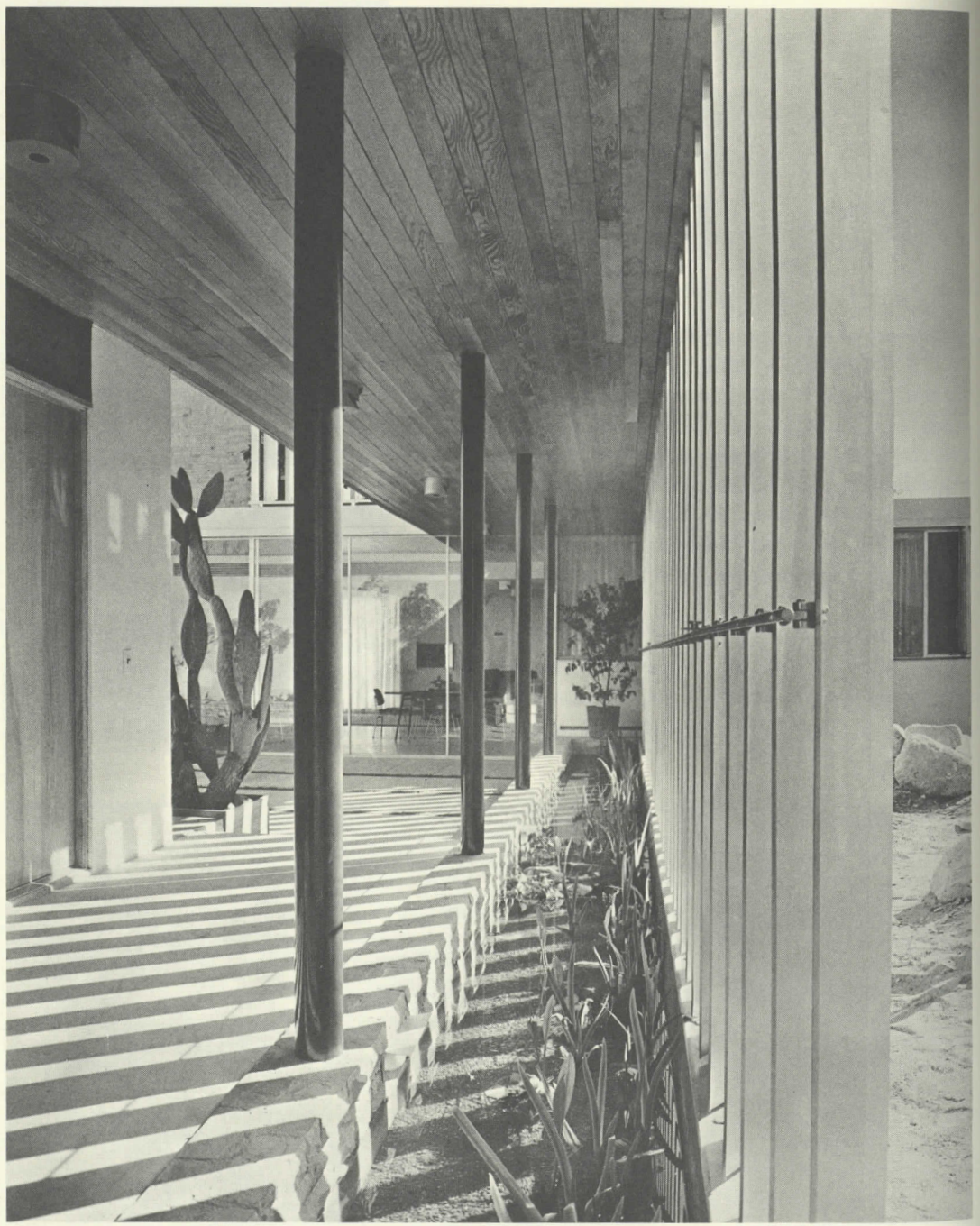


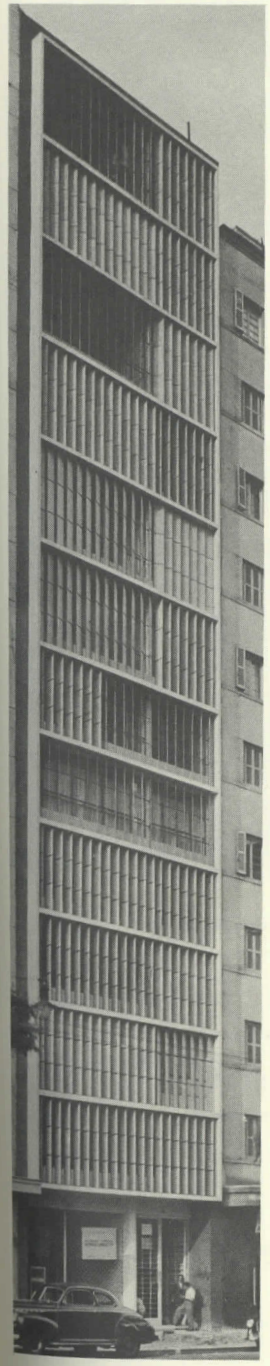
Brilliant sky may offer some 9600 foot-candles of light, but it also produces a reflective brilliance on sand or practically any ground surface. An integration of exterior sun-stops and interior sliding drapes answered this problem.

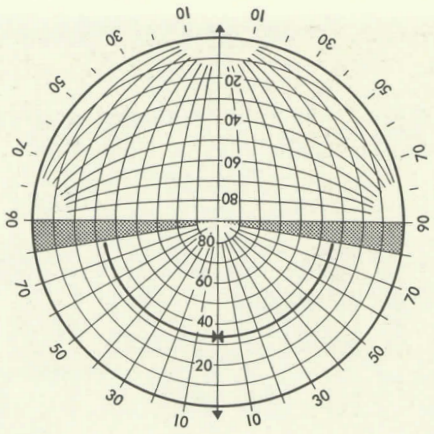
TYPICAL ELEVATION





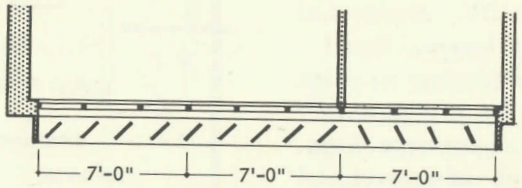




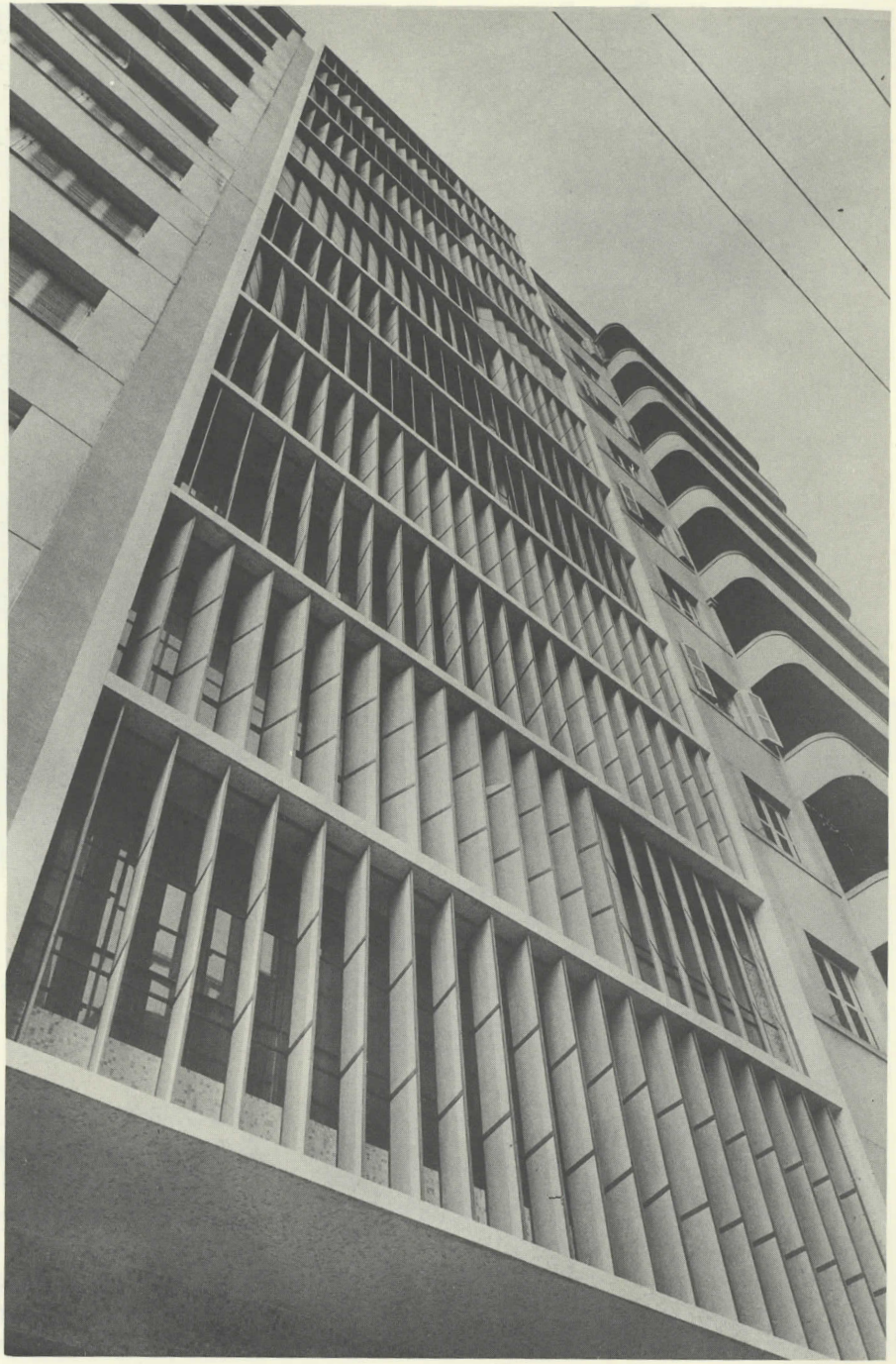


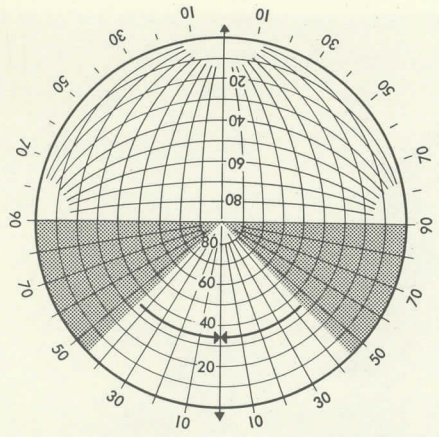
EDUARDO KNEESE DE MELLO, *Cavaru Apartments, Sao Paulo, Brazil*

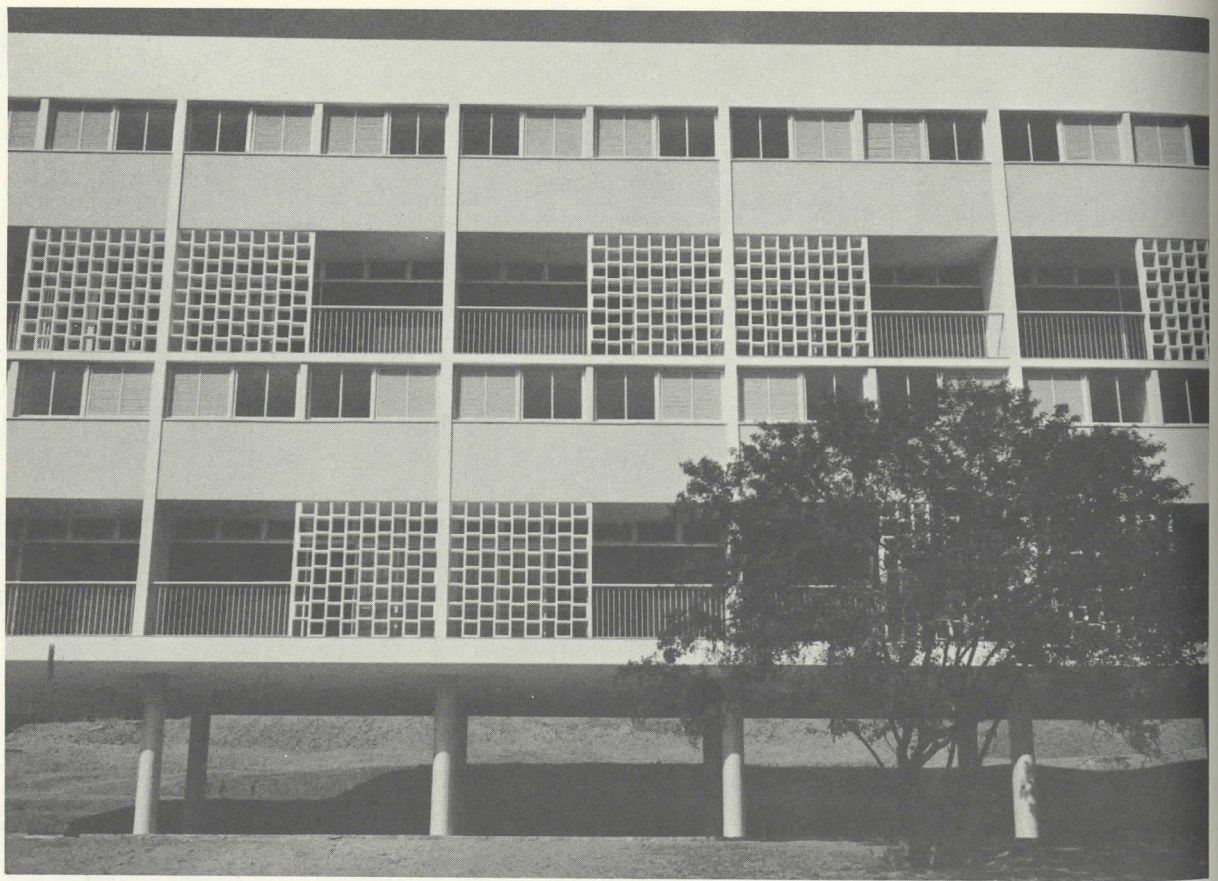
The entire elevation of this apartment house is defined by the character of shading devices used. Vertical fins of asbestos cement are set in steel frames which are attached to mosaic-covered concrete construction. The fins can be adjusted not only on each floor separately but also on one floor in different angles. By this flexibility it gives life and varied pattern to the elevation throughout the day.

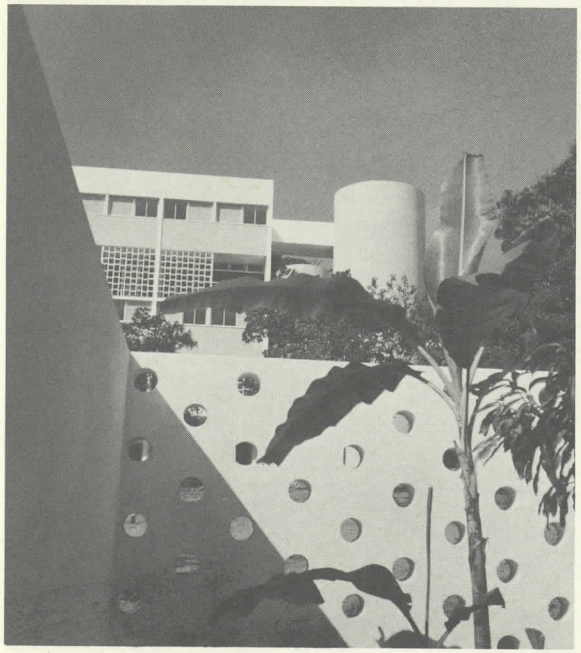


PLAN

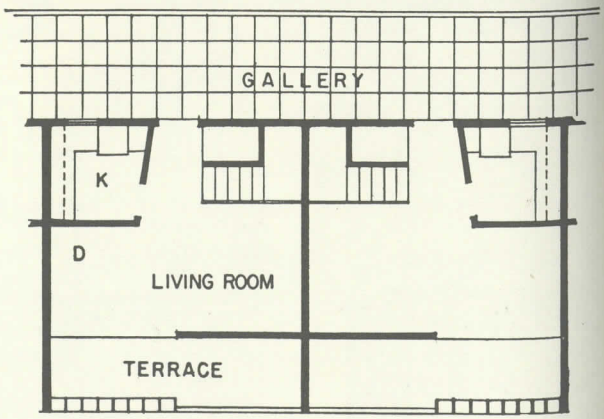




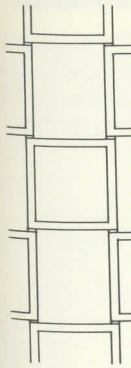




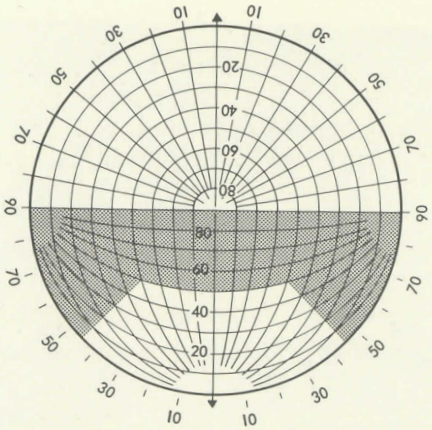
ALFONSO EDUARDO REIDY, *Residential Group in Pedregulho, Rio de Janeiro, Brazil*
A unified facade which in expressing an open grille work along the balconies brings a rich textural contrast to the rigid concrete form. The grille is constructed of salmon-colored baked ceramic squares, 10″ × 10″, and provides a rich interplay of sun and shade.

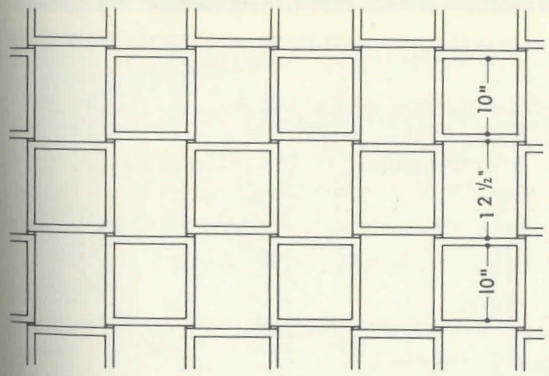


1st and 3rd FLOORS



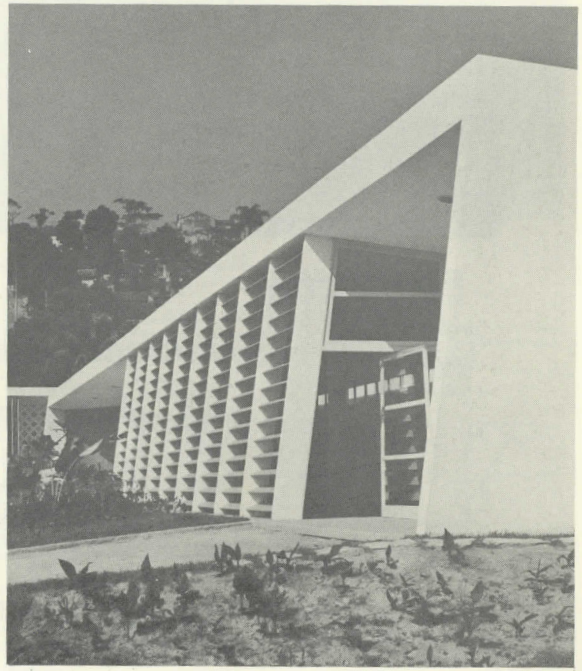
DETAIL OF SC

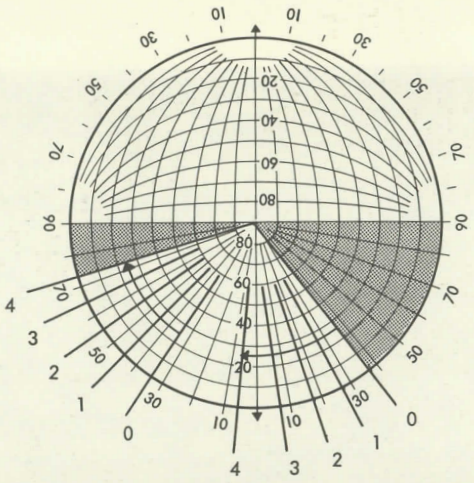




DETAIL OF SCREEN

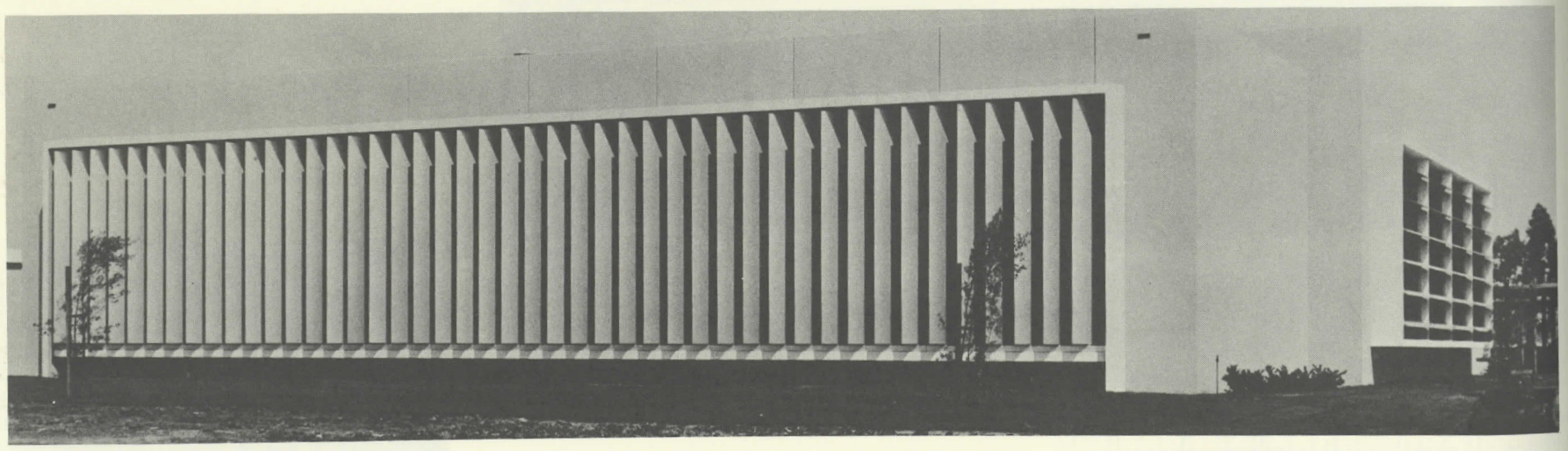
The vertical adjustable fins found on the market building, stores, and laundry are constructed of metal. Their function is to produce variations of light and shade. The contrasts of white trim for balcony rails, louvers, and jalousies, and the yellow accents for doors and windows, provide visual richness.

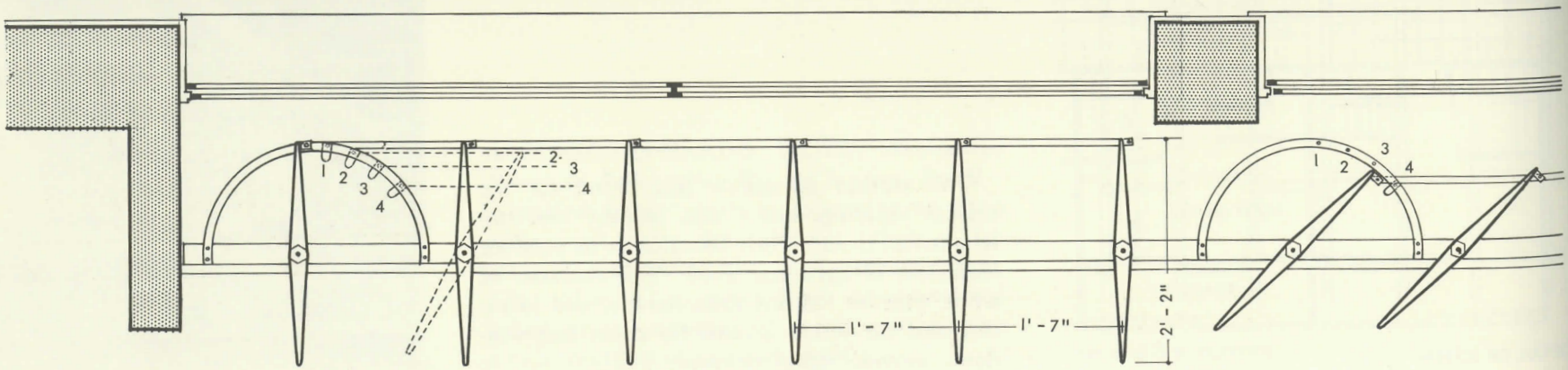




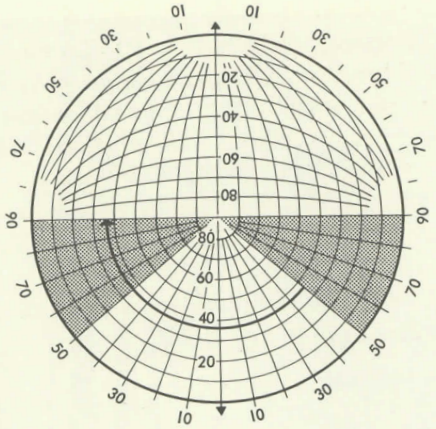
A. C. ZIMMERMAN & T. R. FRIEND, *Harbor Junior College, Wilmington, California*
This building has different weather controls on its elevations according to the orientations. On the longer side movable vertical fins are applied, which are shown in the detail drawing.

The fins can be set to five different positions, which are manually operated and connected in groups. Their positions are changed about every month to exclude the direct sun radiation from the schoolrooms.

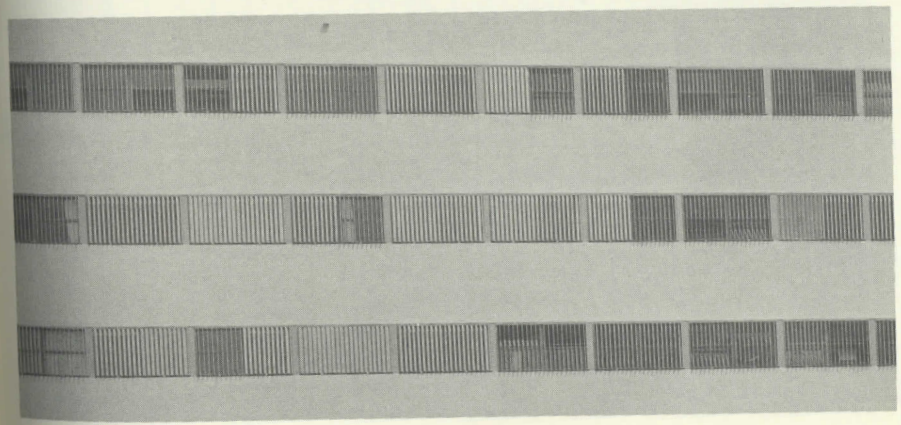


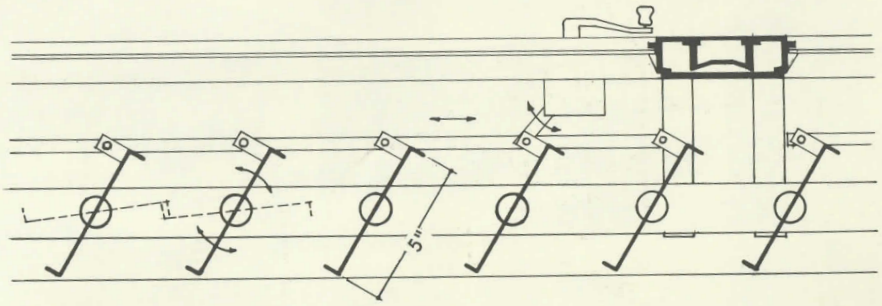


SECTION THRU SOLAR SHADES

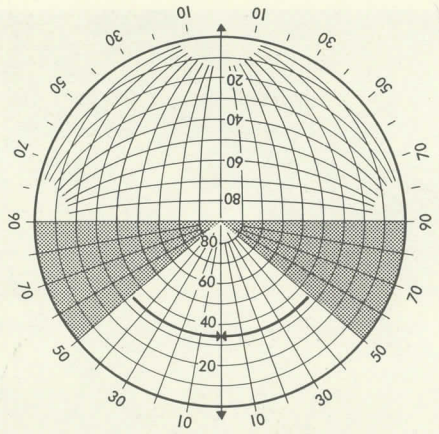


VICTOR GRUEN & KRUMMECK, *Wilshire Medical Building, Los Angeles, California*
This building illustrates the proper use of shading devices: namely, to change their types in different orientation. All windows in the office areas along the south and north sides of the building are protected from the sun by means of exterior vertical or horizontal aluminum jalousies, fully adjustable from the inside. These jalousies stop sun radiation before it can come in contact with the window glass, a critical factor in preventing excessive room temperatures.

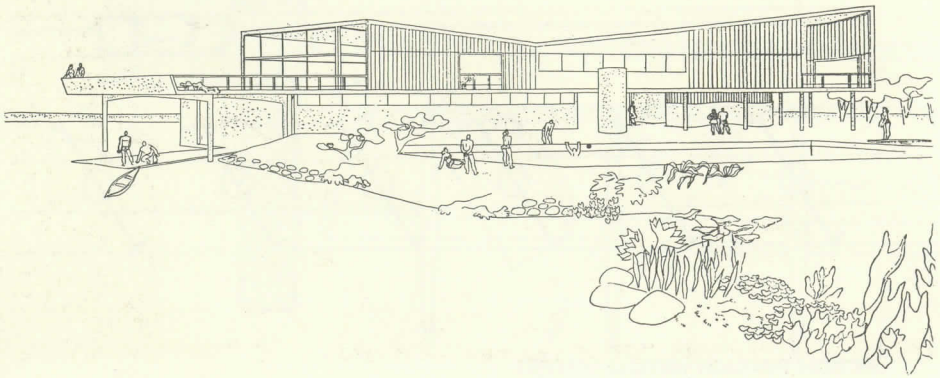


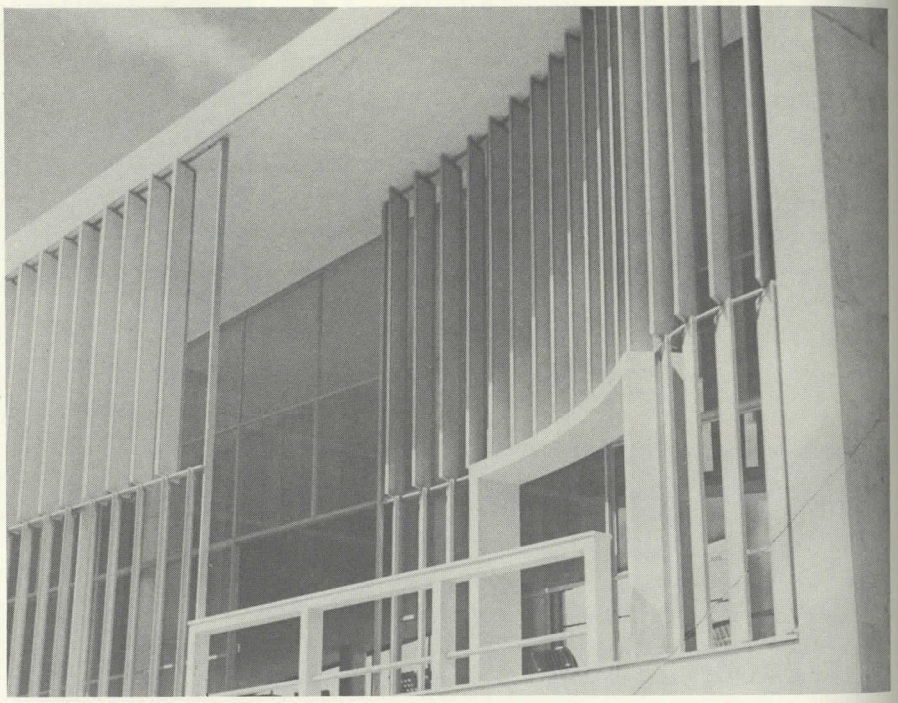


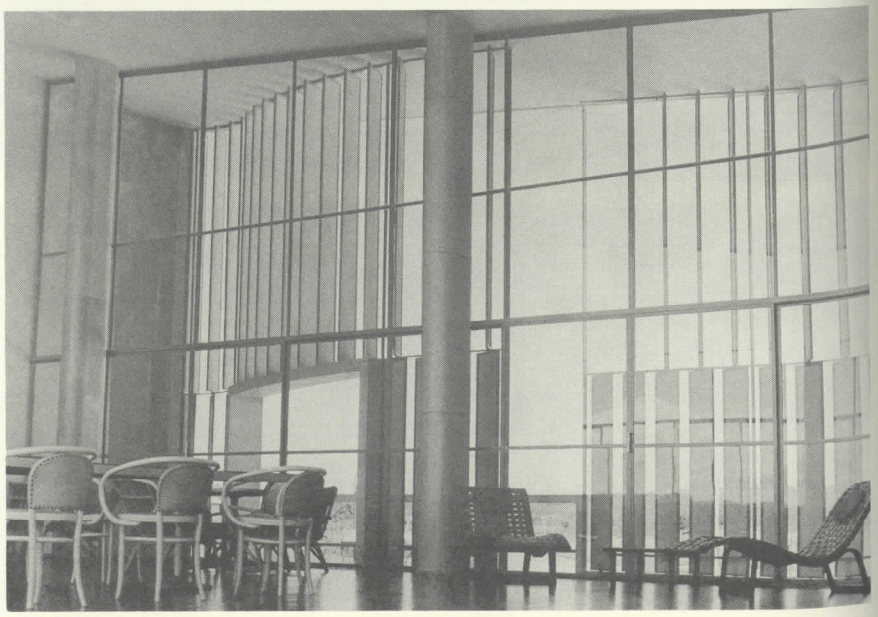
SECTION THROUGH VERTICAL LOUVERS

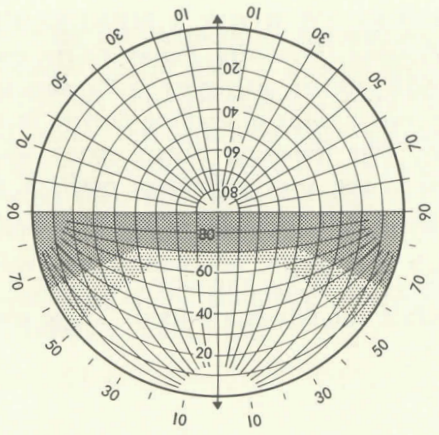


OSCAR NIEMEYER, *Yacht Club in Pampulha, Brazil*
The western elevation of the yacht club which faces a large outdoor swimming pool is protected with a sunshade of vertical adjustable louvers. They are composed of long vertical slabs which are constructed in two ranges, superimposed one above the other. A metal frame allows for a pivoting motion to adjust amounts of sunshine and air, creating at the same time a changing pattern. The detail shows the southern end of the facade, which protects the interior of the lounge.



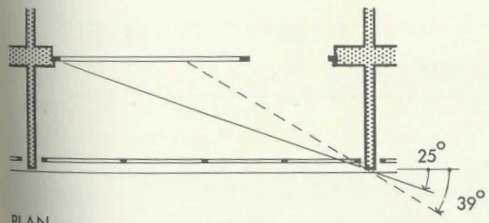




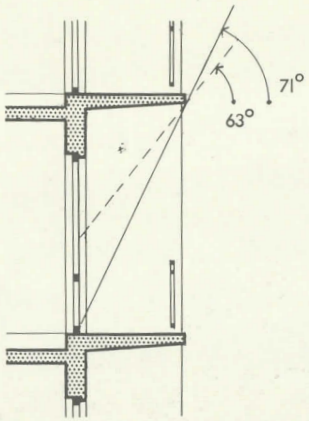


OLGYAY & OLGYAY, ***Apartment House, Budapest, Hungary***

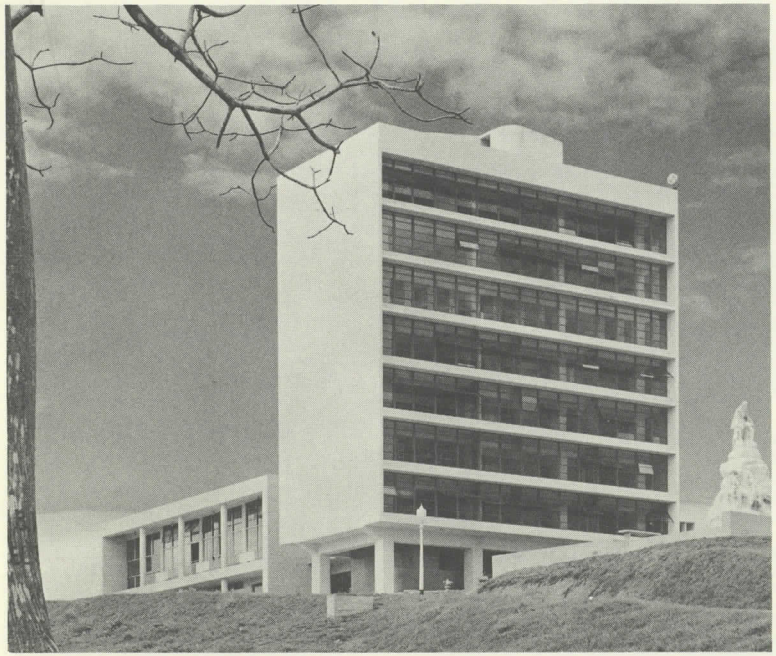
The living areas of this apartment house face toward the southeast and protection was needed against the sun. It was solved with a fixed egg-crate device, which serves another purpose too: to provide terraces for each apartment, while the vertical fins secure privacy. This structure is of thin concrete with plaster finishing. The railing has glass panels.



PLAN

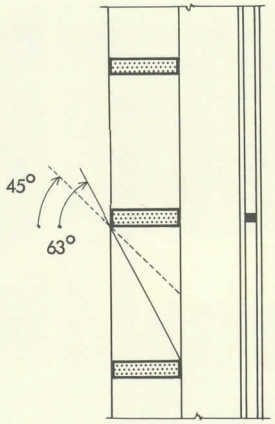


SECTION

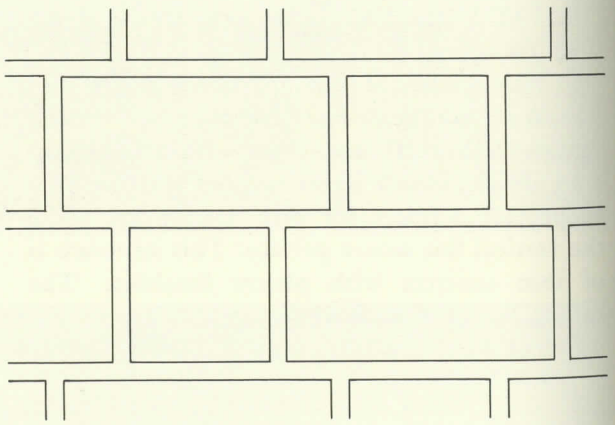


BERMUDEZ, DE ROUX & MENDEZ GUARDIA, *Panama University, Panama City, Panama*
This small modern university in Panama utilizes the expressive value of shading devices in a logical way. The imposing library tower which is situated in the most prominent position, facing north and south, uses horizontal shading devices.

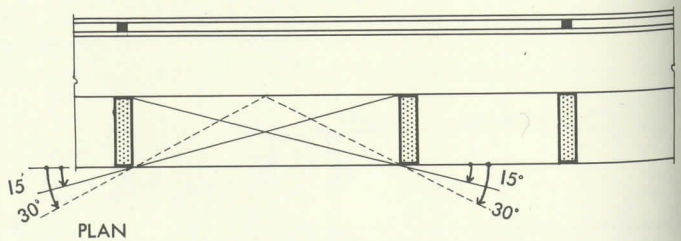
On elevations facing the east and west, a series of eggcrate sun-blinds are used. These concrete



VERTICAL SECTION

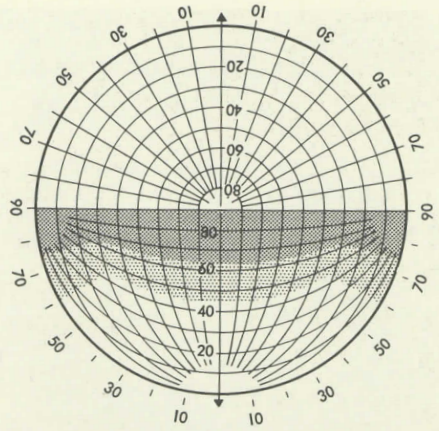


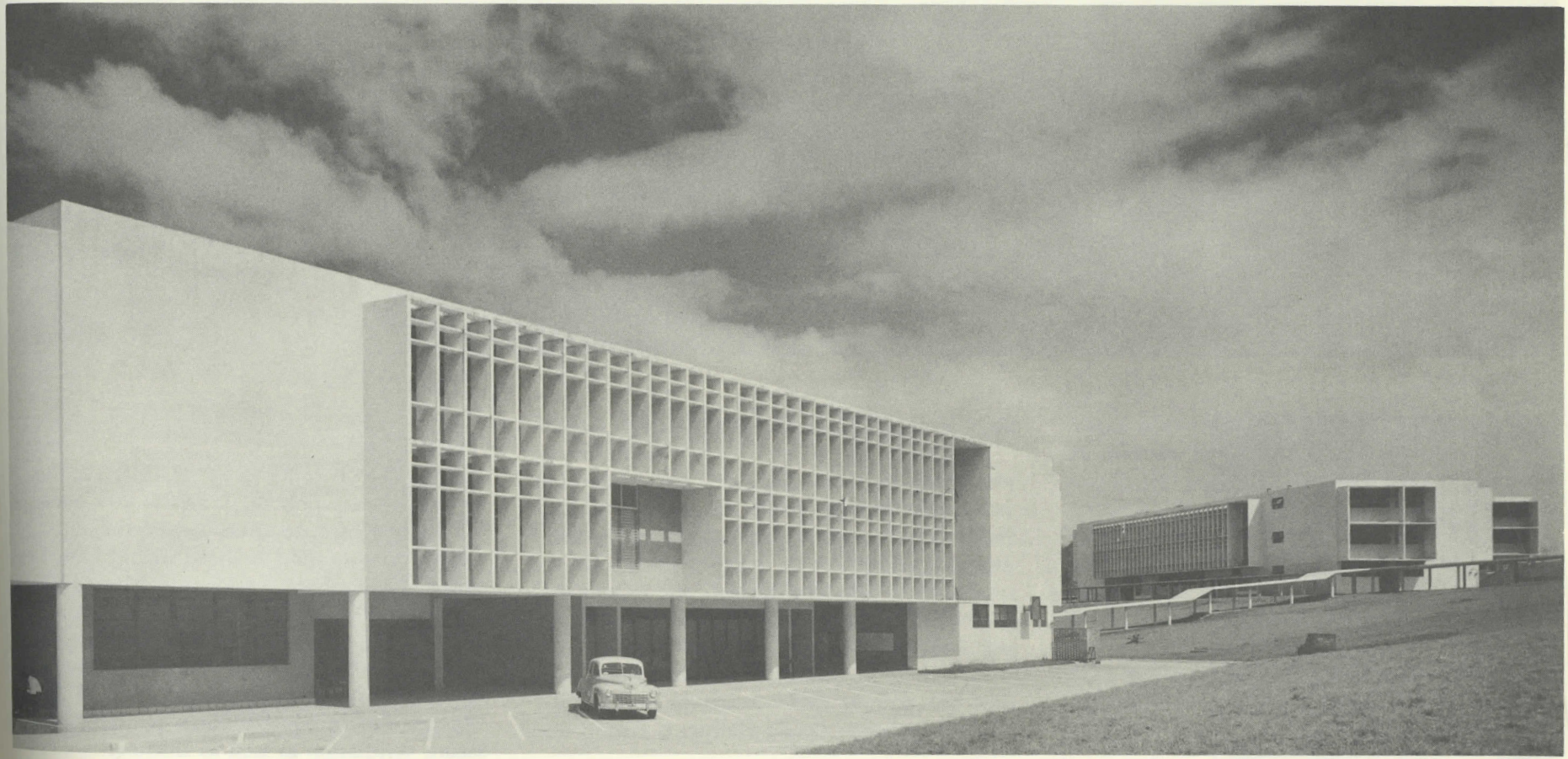
ELEVATION

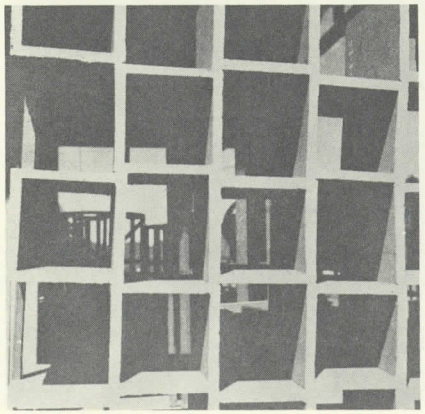


PLAN

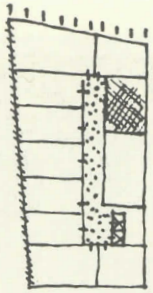
motifs define the character of the whole campus architecture. One of these is a large eggcrate of *brise-soleil,* set between stretches of blank wall, behind which the architects have managed to find a way of concealing large lecture rooms that in turn get their light from the narrow facades. Another architectural feature is the ribbon-canopies that thread their way all through the campus, uphill and down, from one building to the next, securing shaded walks.

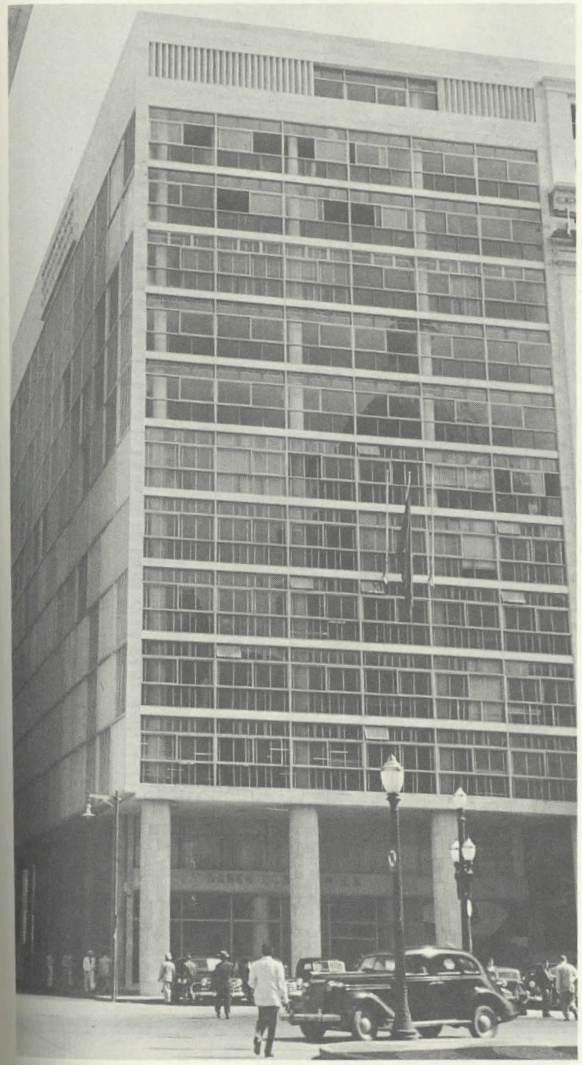


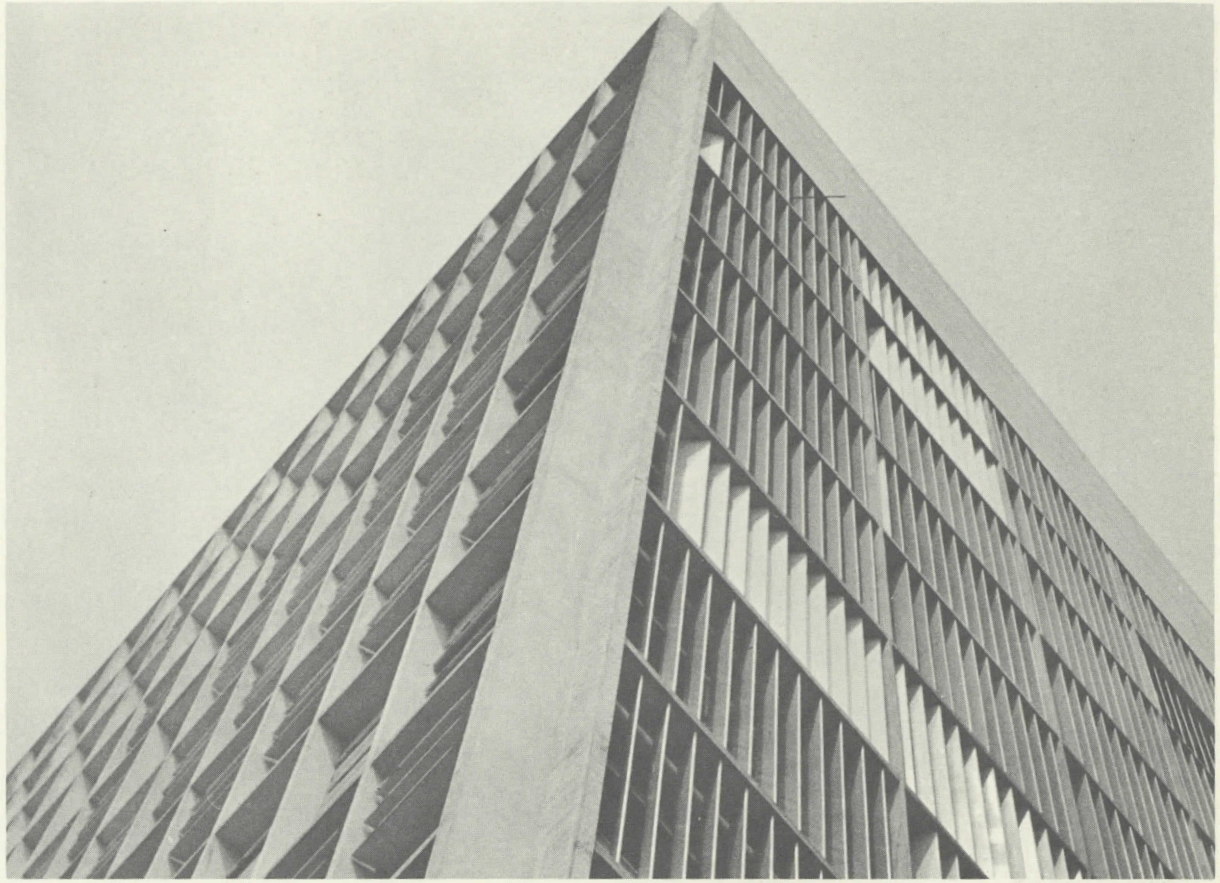




P. L. WIENER, J. SERT, P. SCHULTZ, *Neighborhood Unit, Habana, Cuba*
This group of apartment houses, and one of a series of houses were designed for "Quinta Palatino" neighborhood unit in Habana, planned for about 10,000 people. The most striking element of the elevations is their perforated character; the concrete grills which the same architects, the Town Planning Associates used for the "Cicade dos Motores." These perforated walls secure ventilation as well as shading.





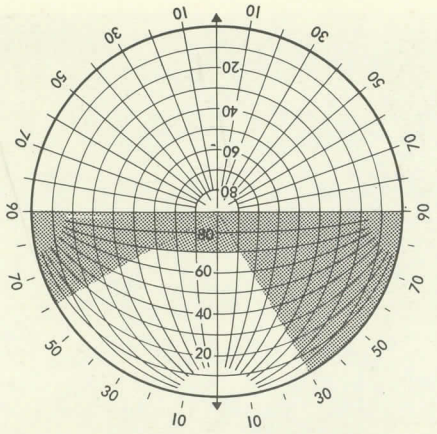


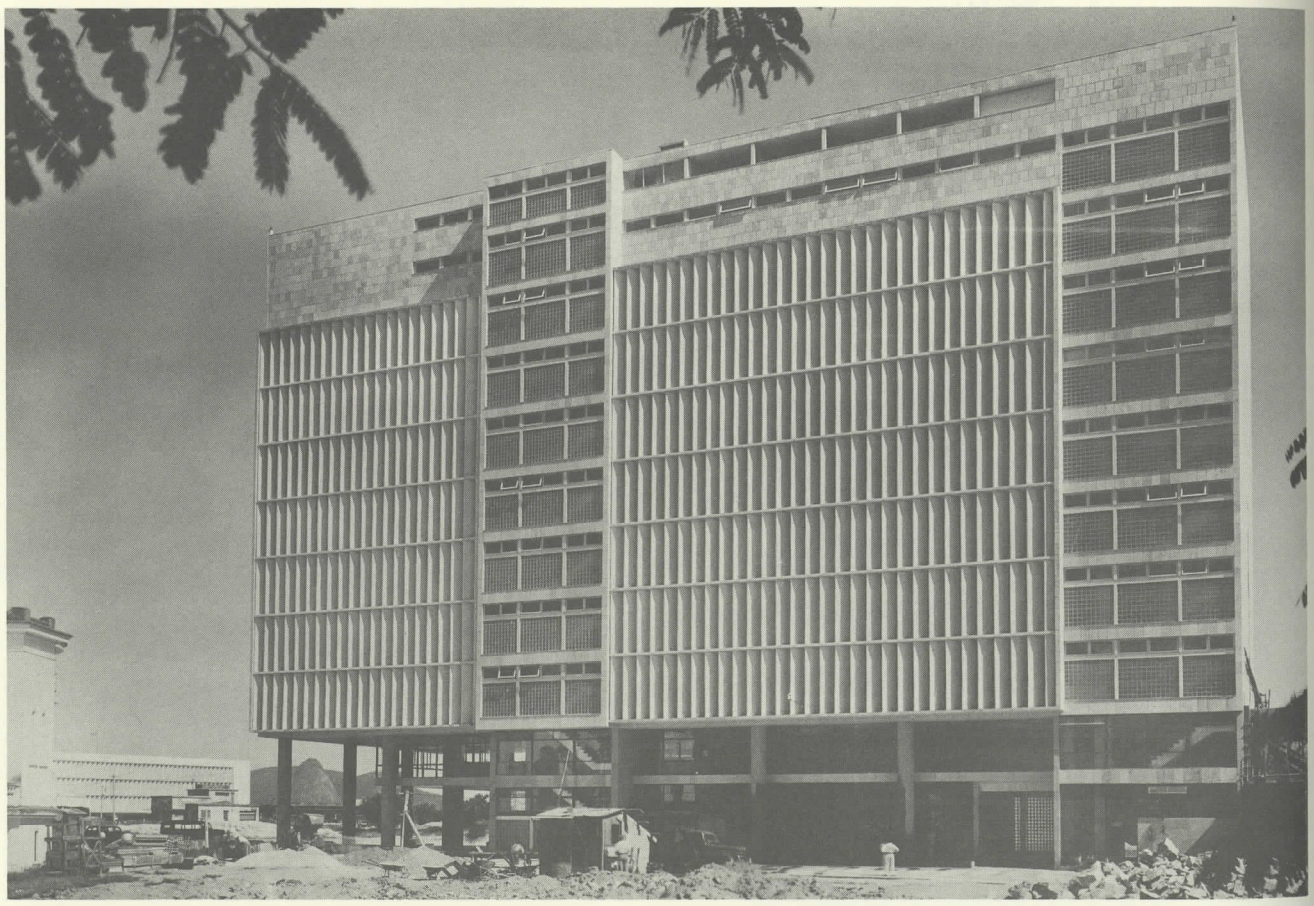
OSCAR NIEMEYER, *Boavista Bank, Rio de Janeiro, Brazil*

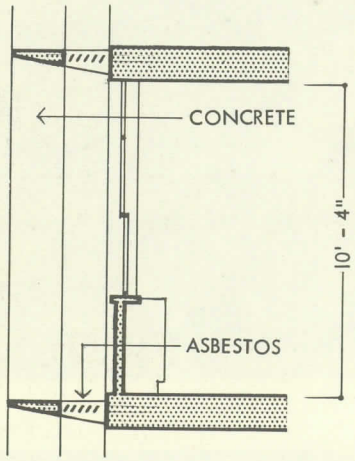
This multi-story building, built in downtown Rio de Janeiro has three exposed elevations. These elevations facing in various directions are treated accordingly with three different textures. It is one of the clearest examples of this functional treatment, which is further enhanced by a first floor setback so that the other wall surfaces become clearly defined.

The south elevation which receives the least heat impact is entirely glazed, showing the reinforced concrete frame. The north elevation has an eggcrate frame with movable horizontal louvers inside, which gives the whole elevation horizontal character. In contrast to this, the west elevation which faces a narrow street is equipped with sun-shades of vertical louvers. Because this facade is on a narrow street, the louvers on the lower floors assure privacy in the offices.

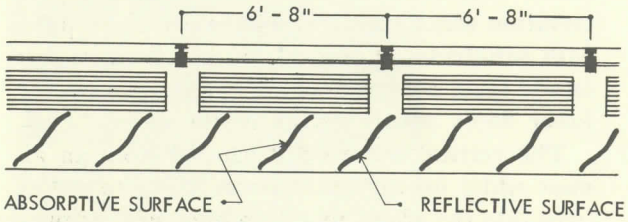
The vertical louvers are painted from an almost white on the lower floors, so as to reflect light into the offices, to a deep blue on the upper floors for light absorption.







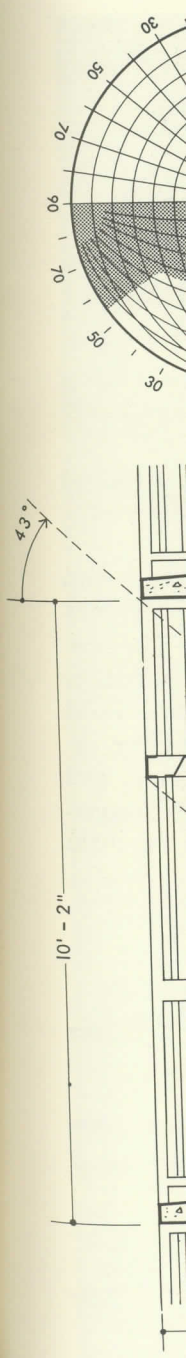
VERTICAL SECTION



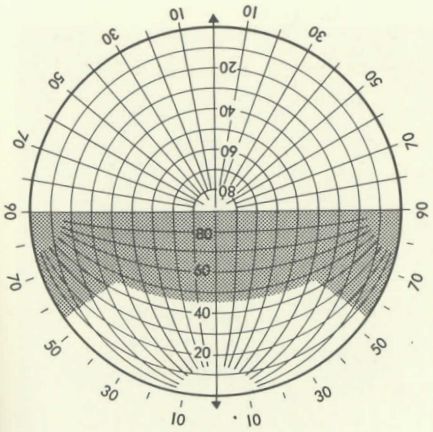
PLAN SHOWING VERTICAL FINS

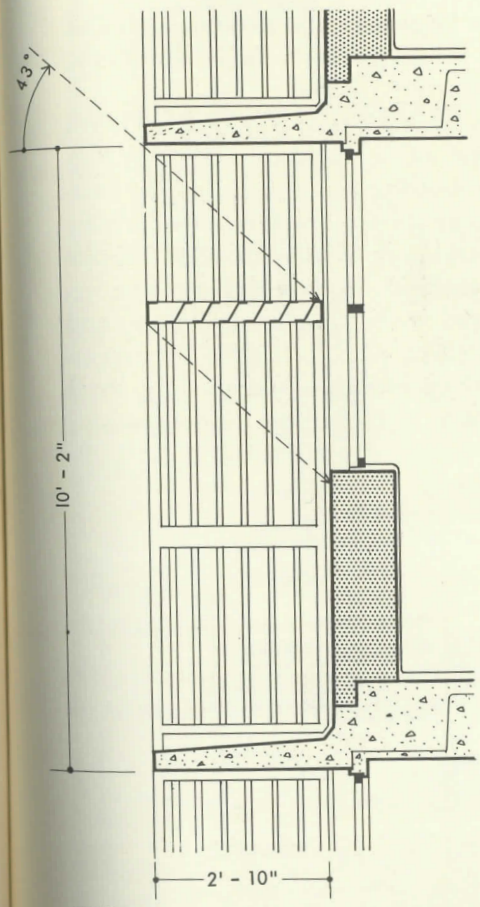
M. M. M. ROBERTO, *I. R. B. Building, Rio de Janeiro, Brazil*

This reinforced concrete office building has its floor cantilevered out beyond the wall which supports fixed vertical shading devices. Each device is separated from the wall with a heat-dispersion space, which in turn is provided with sun-shade protection against the summer sun-rays. The fins are so placed as to provide an absorptive surface toward the building and a reflective surface away from the building.



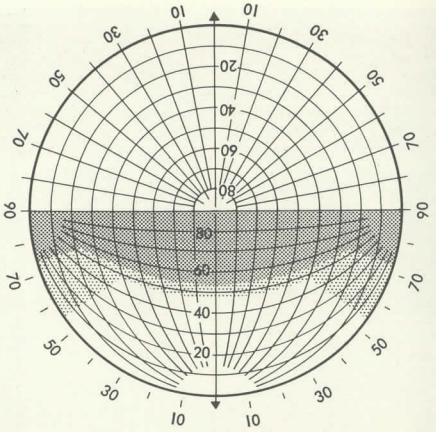
SECTION





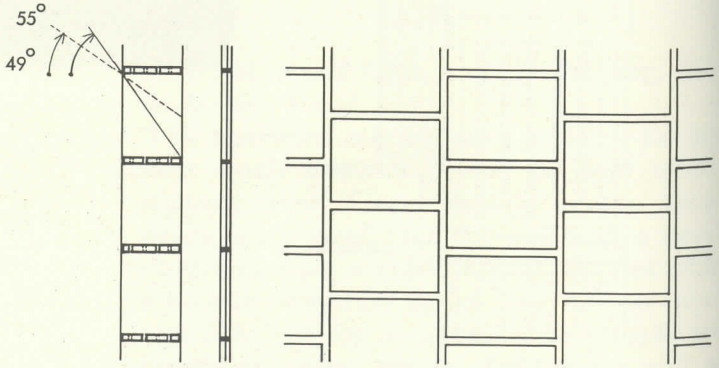
SECTION

STEVENS & WILKINSON, *Georgia Baptist Hospital, Atlanta, Georgia*
Protection from solar radiation is achieved on the east and west facades of this L-shaped building by a grid system of concrete and metal projections. The concrete floor is extended to produce a concrete eyebrow, and inserted vertical and horizontal aluminum fixed fins deflect the sun rays.

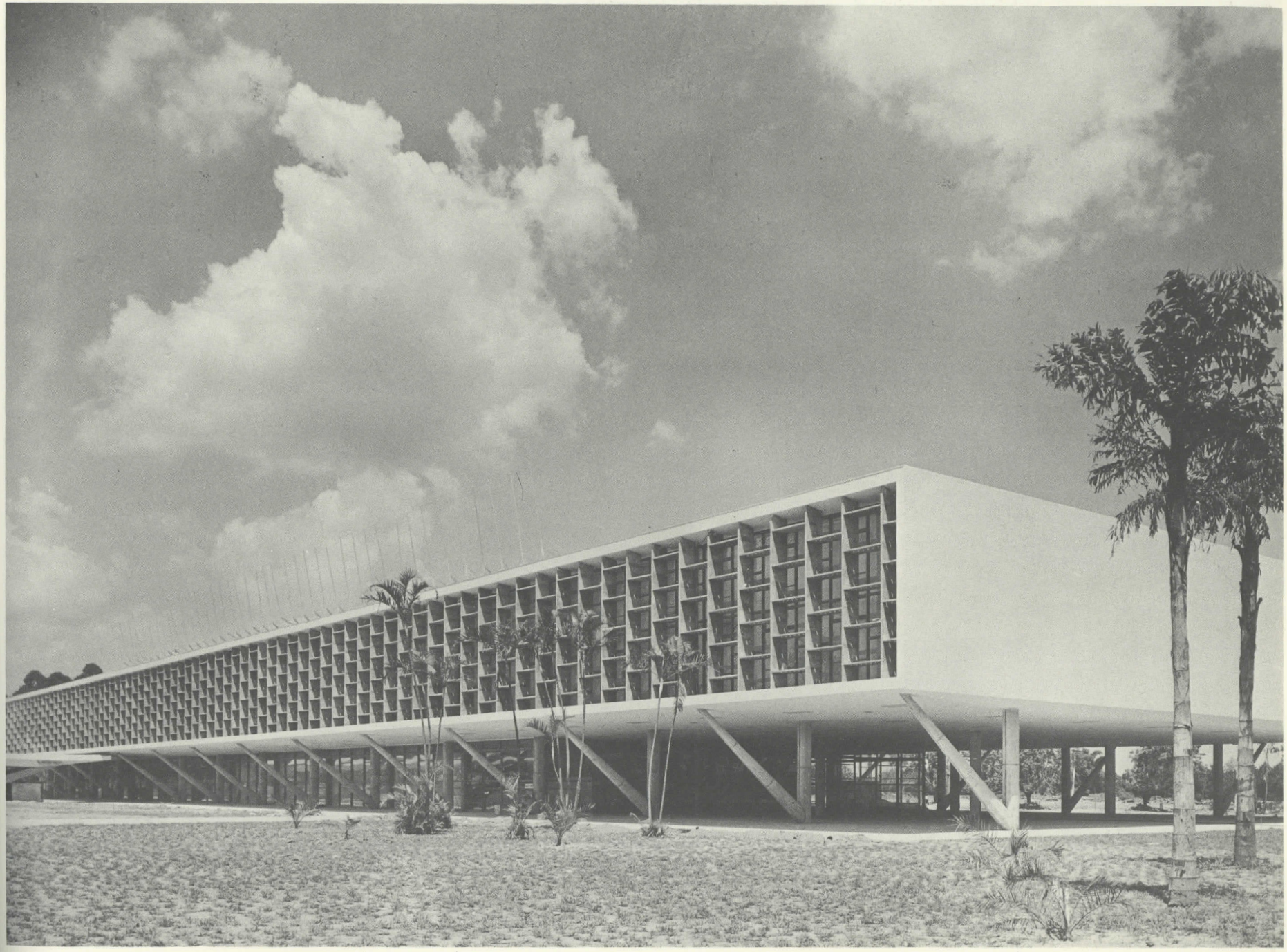


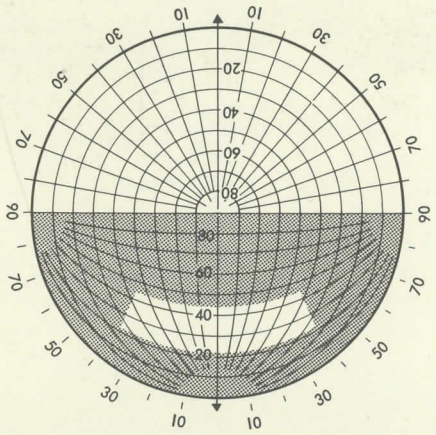
NIEMEYER, UCHOA, COTUFO, KNEESE DE MELLO, *Palace of the Nations, Sao Paulo, Brazil*

The Palace of the Nations in Sao Paulo's Fourth Centennial Fair was a cooperative work of Niemeyer, Uchoa, Cotufo, and De Mello. The clarity of rectilinear form is further enhanced by the uniform treatment of its sides, of which one is covered with fixed eggcrate devices. The device is separated from the glass enclosure, and has a vibrant effect, partly achieved by staggering the horizontal elements and piercing them with small holes.



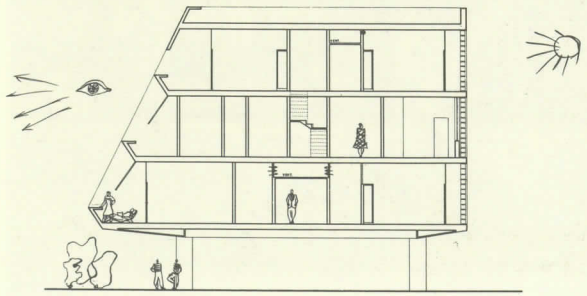
VERTICAL SECTION ELEVATION

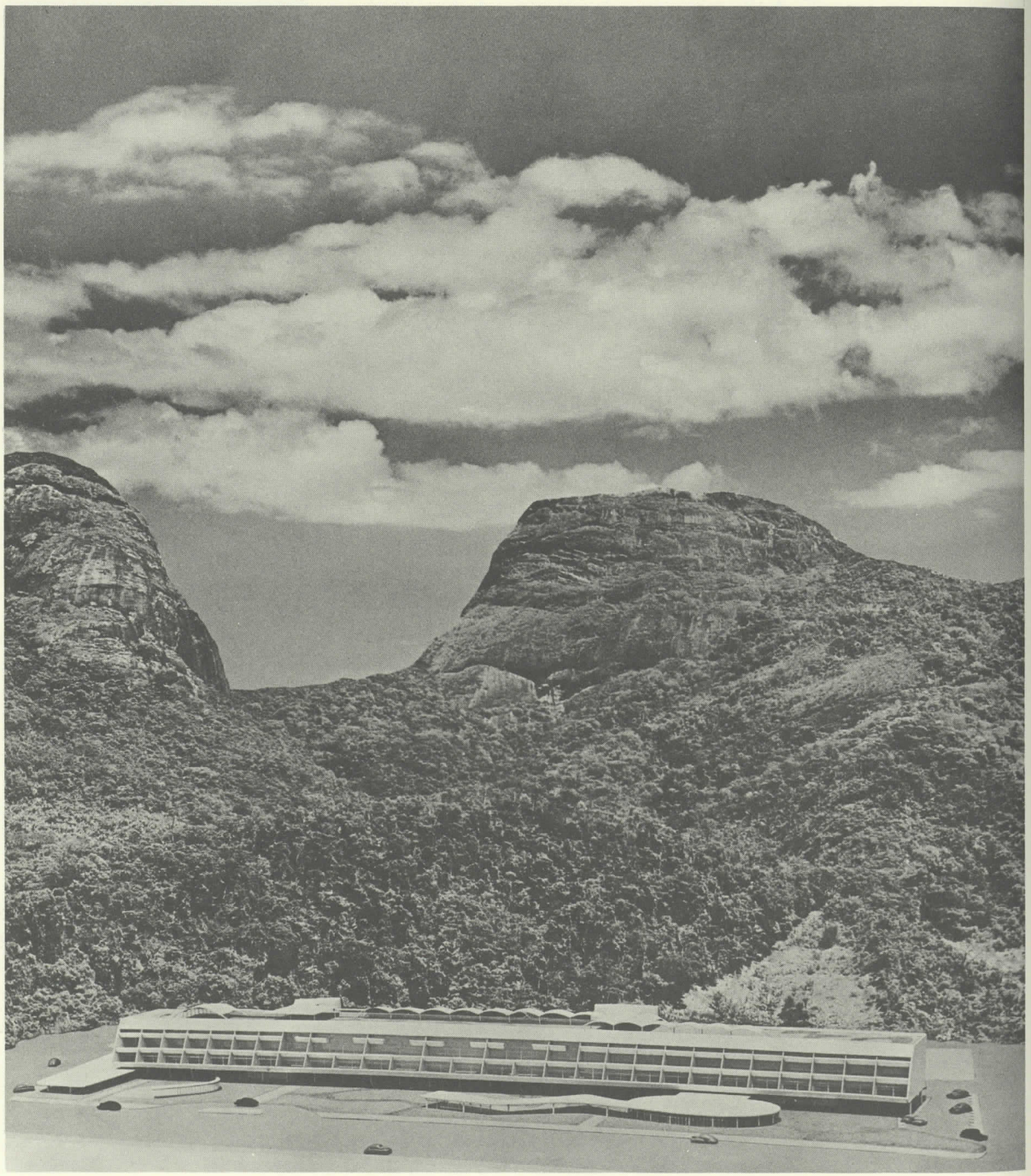


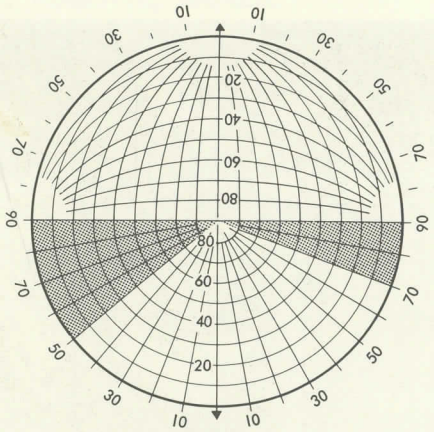


OSCAR NIEMEYER, *Hotel Regente, Savea, Brazil*

Hotel Regente is a resort hotel with 170 apartments now under construction. The pictures are taken from a model, showing both sides of the building. Its elongated form is closed at the ends, and is treated with an eggcrate shading device toward the sunny side, and with horizontal balconies, separated with a slanting concrete wall, toward the sea. The shading mask shows the characteristics of the latter. The two upper floors provide duplex units; each one facing the open view has its own balcony.

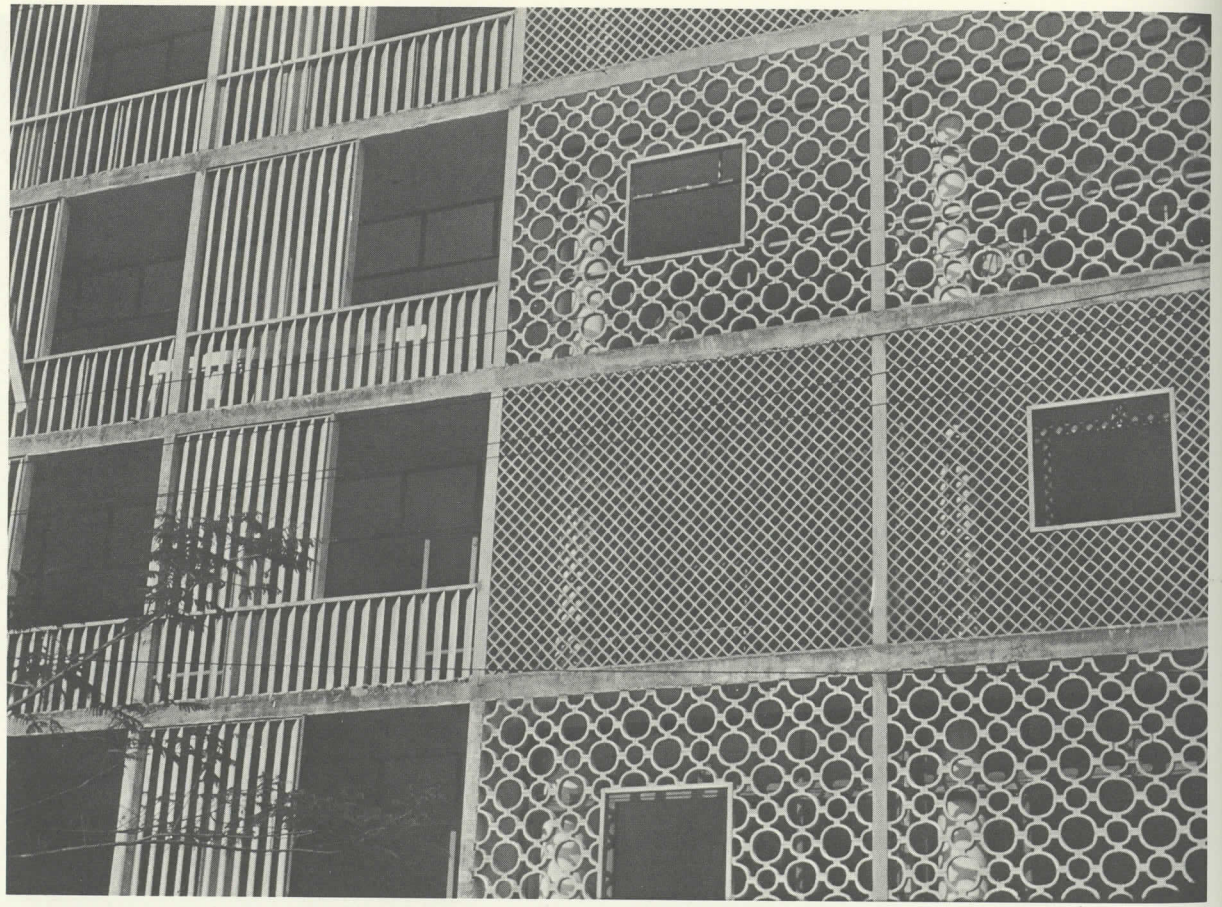


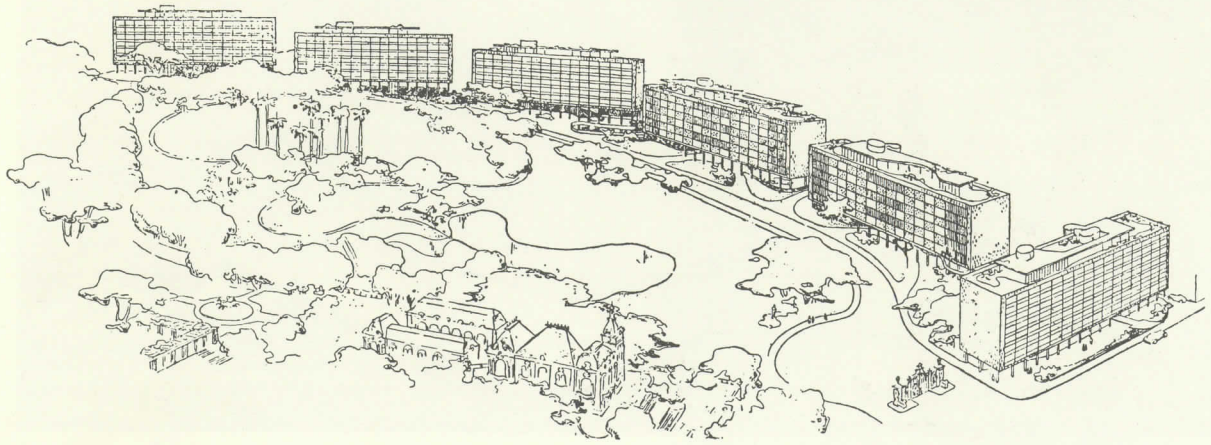




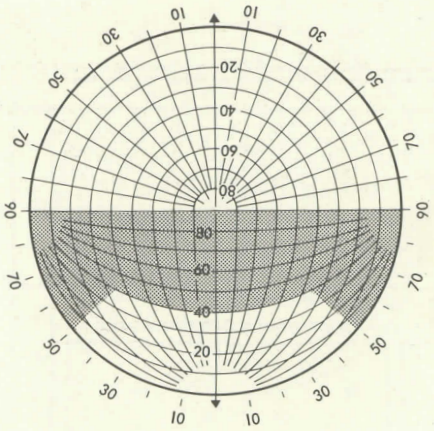
ARMANDO F. COSTA, *Guinle Apartments, Rio de Janeiro, Brazil*

All divisions on the rear elevation are protected by either verandas or terraces. With the intense insolation of the southern hemisphere striking this north side, a system of fixed *brise-soleils* of fibro-cement, set at an angle of 45° to the facade, and panels of specially designed ceramic grilles were used to protect the service and living spaces. Suitable flora will eventually spread over the grilles and will still further reduce the intensity of the Rio de Janeiro daylight.



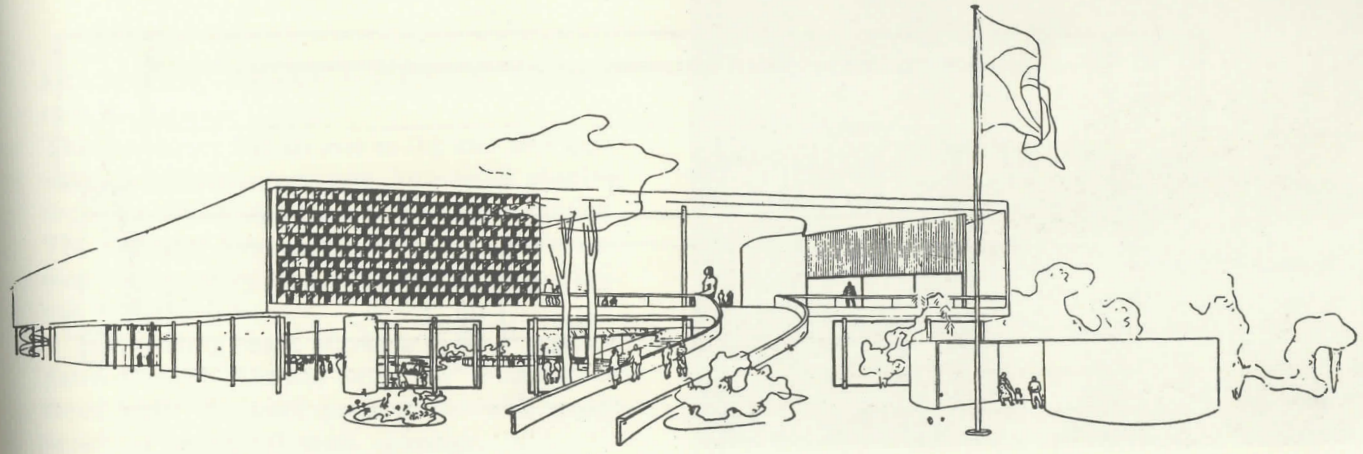


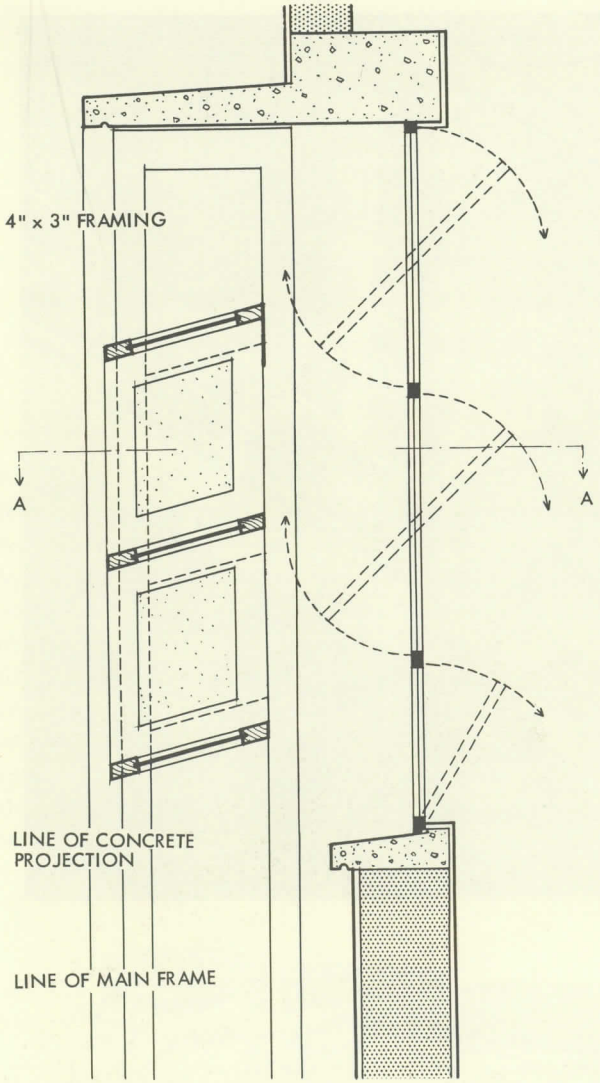
The scheme for building six blocks in Eduardo Guinle Park, as it will be when completed. The two blocks on the right are finished. Another one is now under construction. In the foreground, surrounded by gardens, is the original mansion, with a lake between it and the apartment houses.



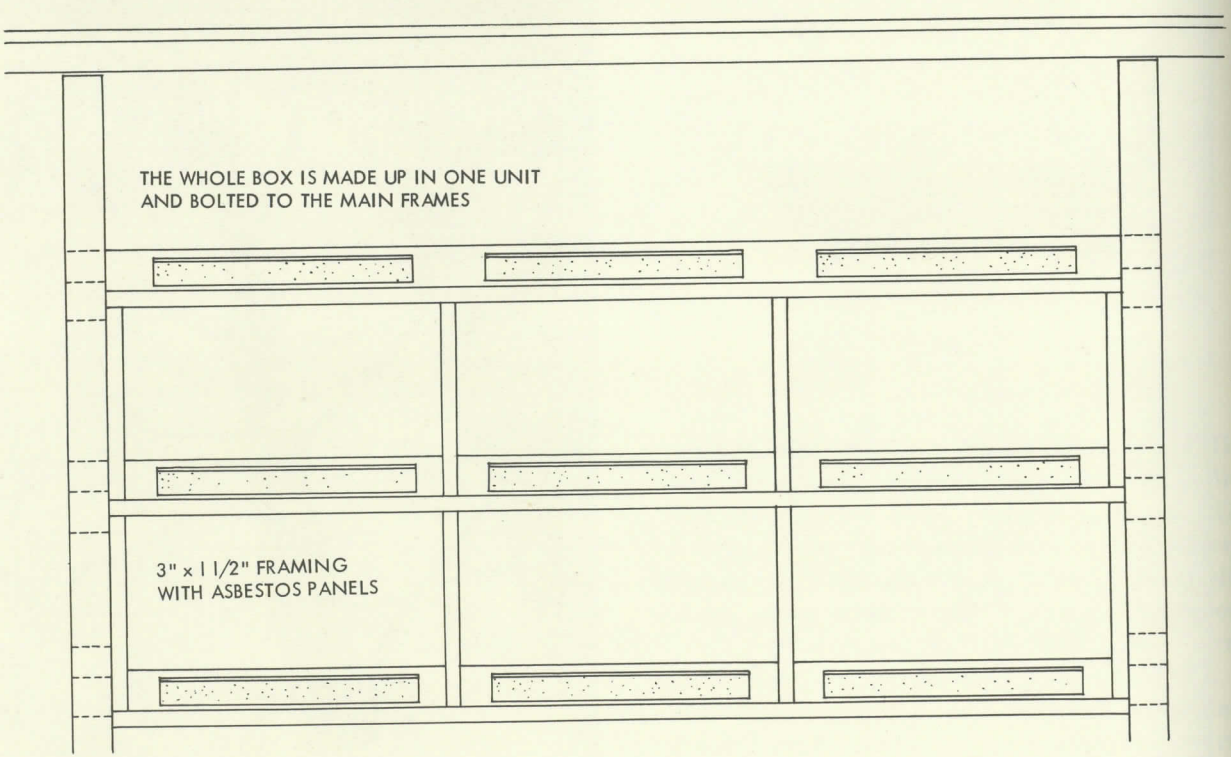
NIEMEYER, WIENER, COSTA, *Brazilian Pavilion, New York World's Fair, New York*
The Brazilian Pavilion shows not only an integration of flora and fauna of the country, with a lily pond, a snake pit, an aquarium, an orchid house and an aviary, but exhibits on its southern facade a fixed eggcrate sunshade.

A curved canopy protects the main exhibition hall from the sun. The "Camboge" sun-break serves to keep the sun from the offices behind, without losing the effective light.

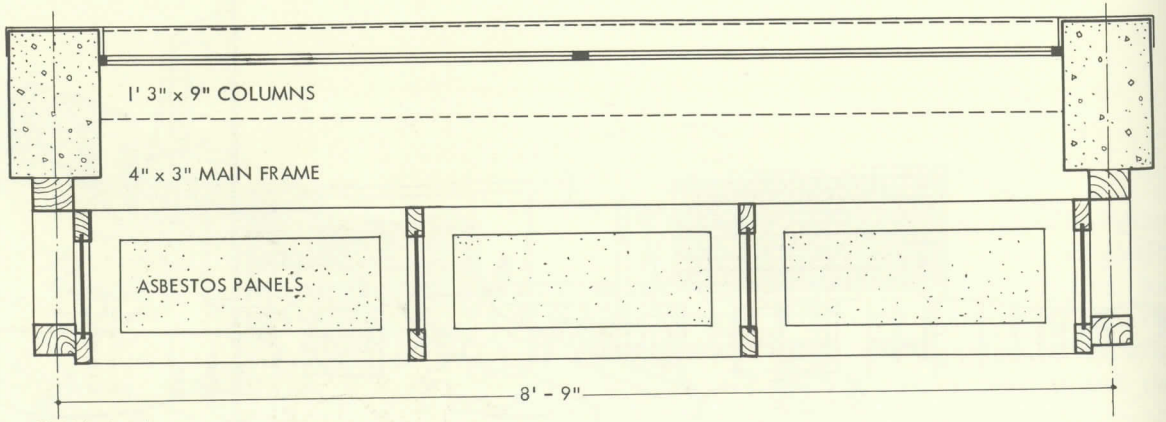




SECTION

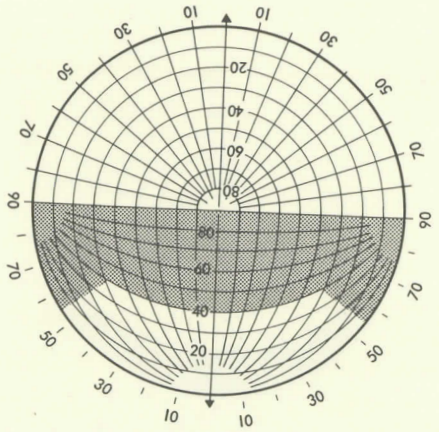


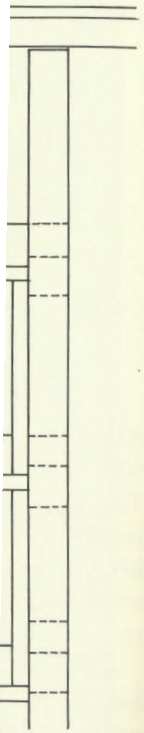
ELEVATION

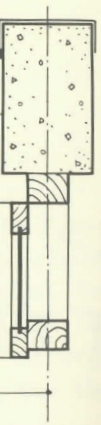


PLAN A - A

The shading device is made of wood frames with asbestos panels attached. The frame is an independent unit projecting from the concrete construction, therefore this eliminates the heat transfer from the device and assures air circulation between the building and the wood frame.



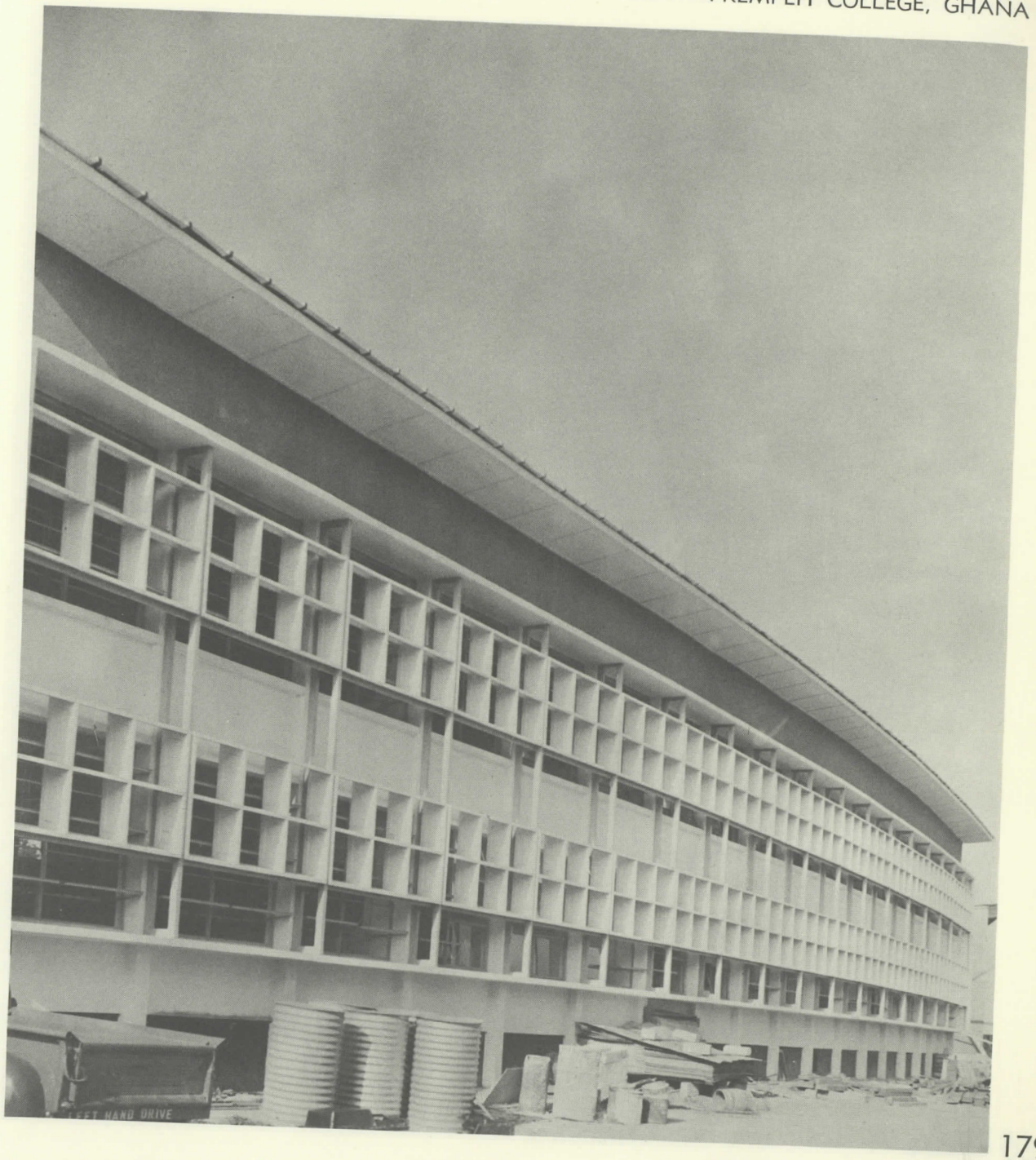


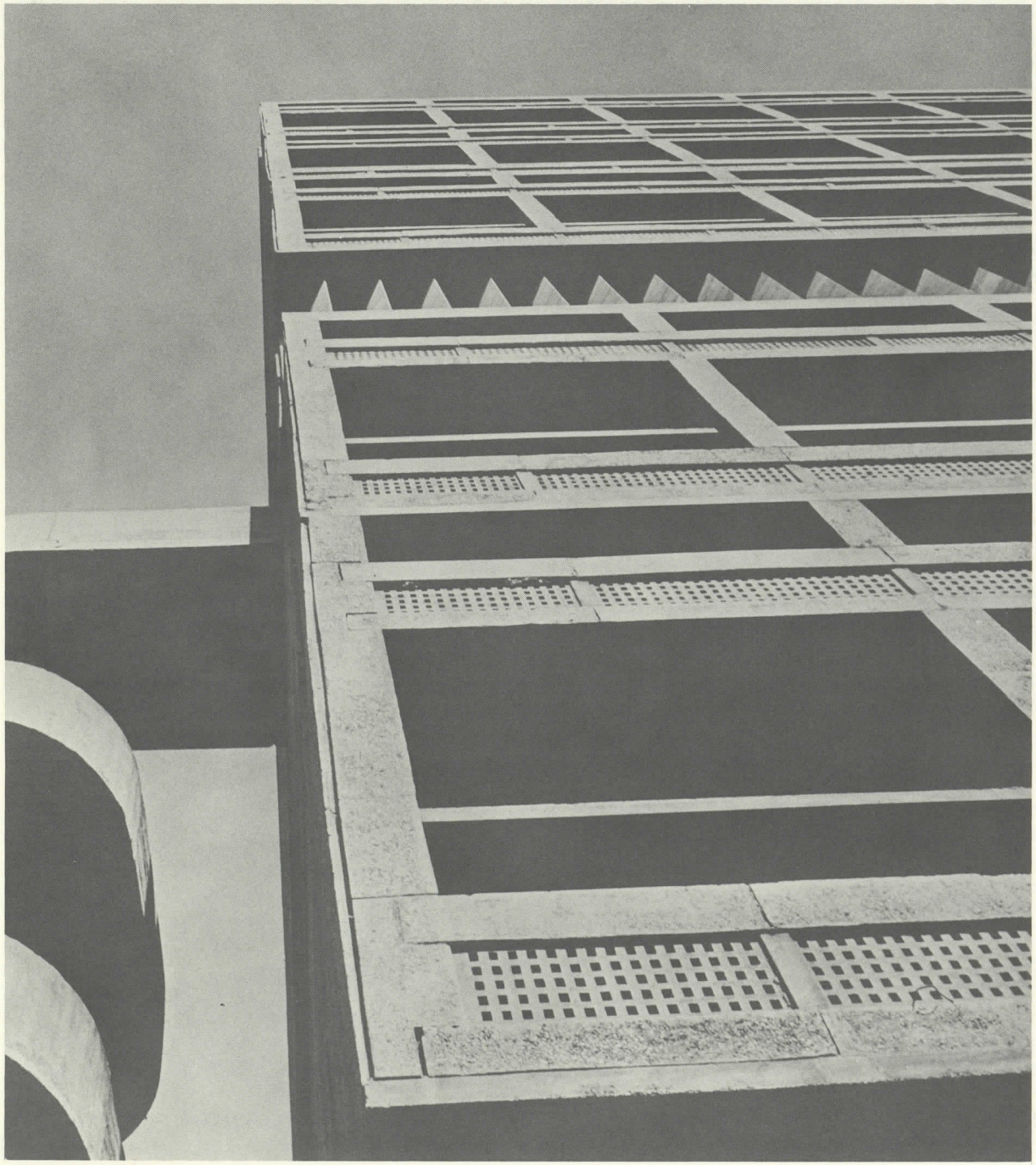


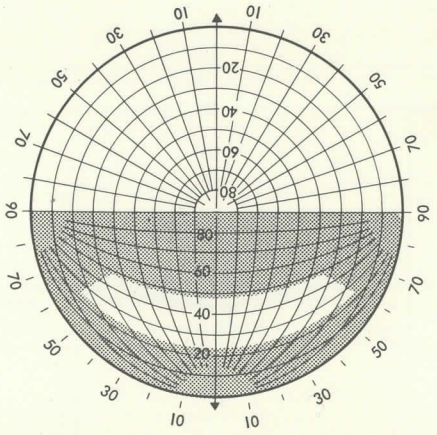
FRY, DREW, DRAKE & LASDUN, *Prempeh College, Kumasi, Ghana*

This dormitory has an axis to the east and west, with an elaborate eggcrate *brise-soleil* shading the south facade against major sun penetration. The northern facade, which during certain seasons is affected by sun, is protected by continuous covered walks.

The shading mask shows a typical eggcrate pattern which protects only the window surfaces, while the solid parts of the wall would receive a segmental mask coverage.

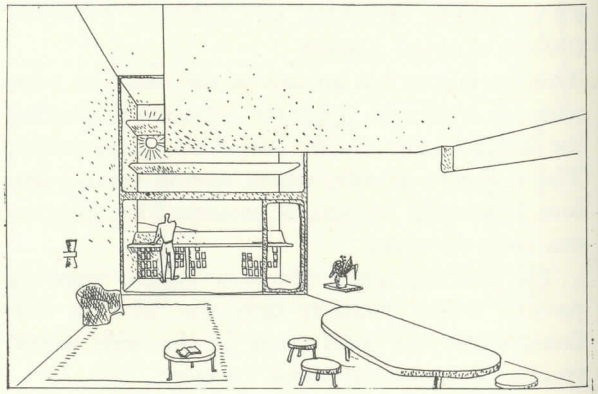






LE CORBUSIER, *Apartment House, Marseille, France*

The "Unite d'Habitation," as le Corbusier calls this type of apartment house which appeared for years in his various projects, was finally realized in Marseilles. The principles of an independent framework, a free facade and the freed ground beneath the house are clearly expressed. It is a middle-corridored arrangement with dwelling units on both sides. Most of the units are duplex-types, which reduces the corridors, or "interior roads," to every third floor.



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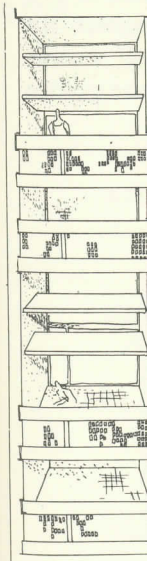
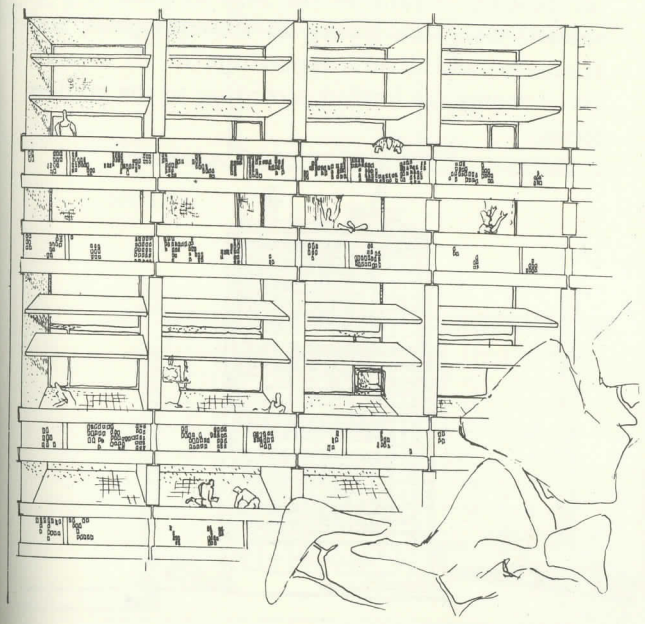
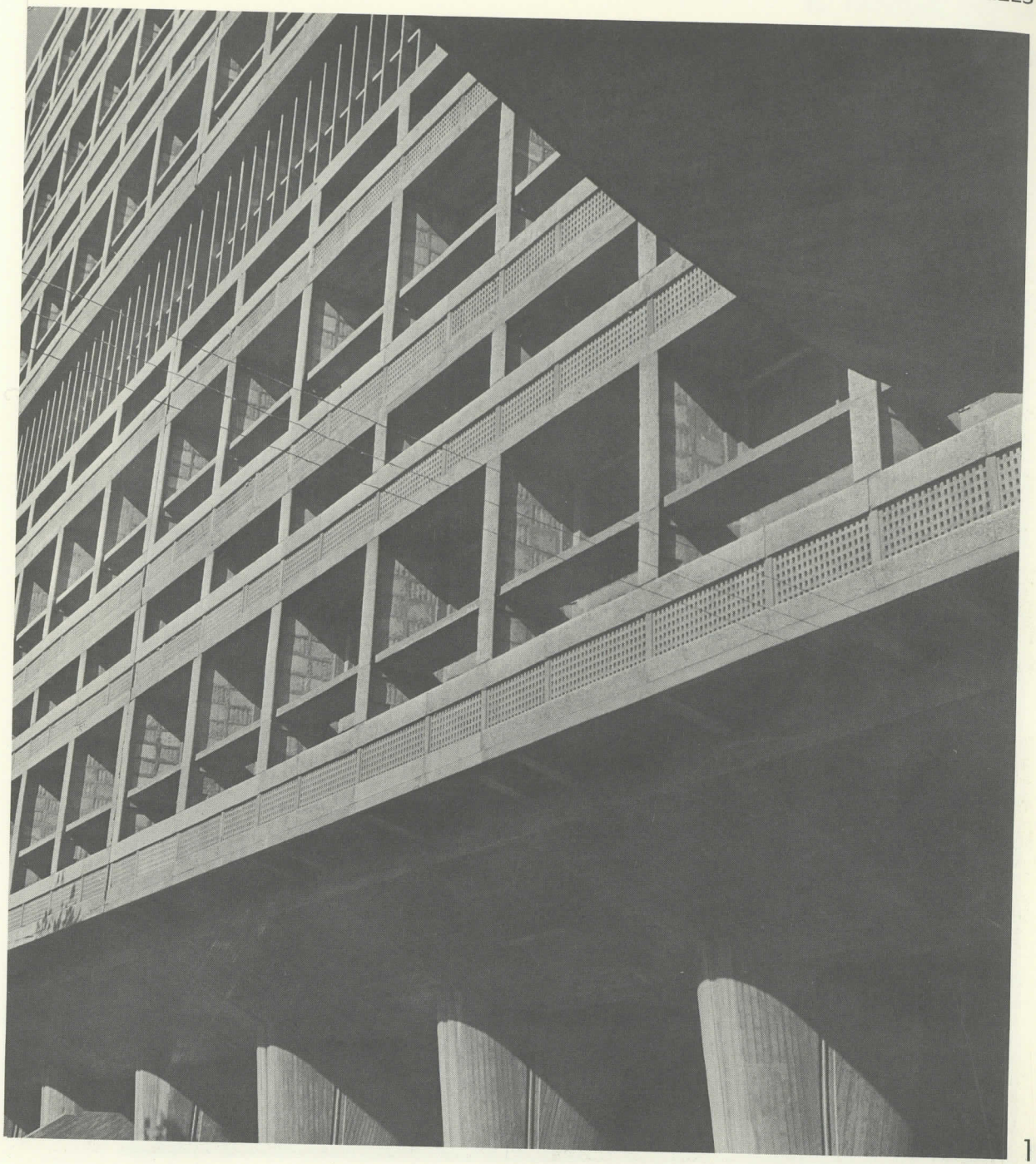
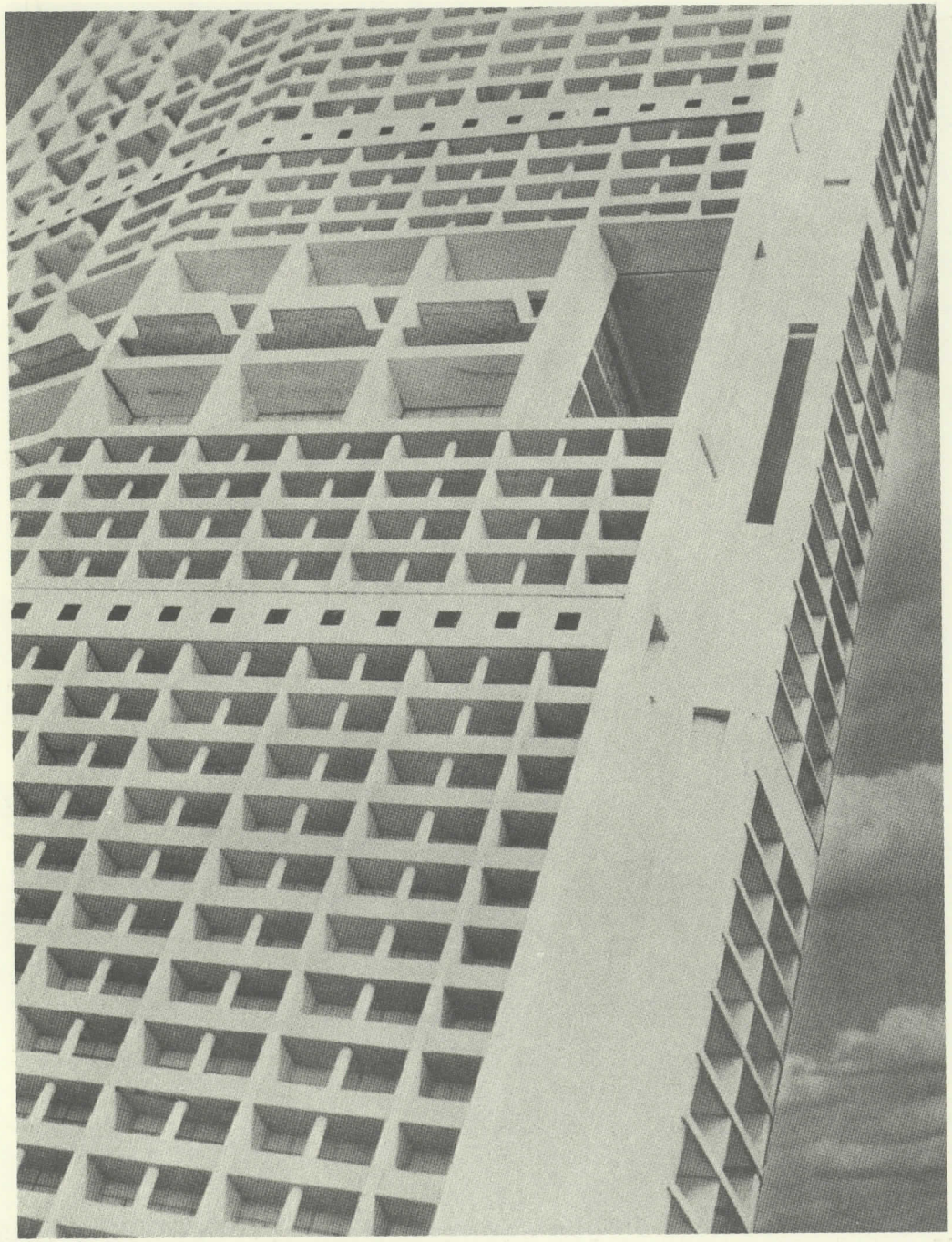
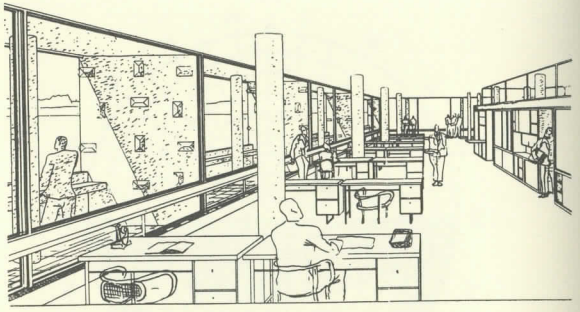


Before the glass skin, "loggias" are placed which act as sun-breakers or *brise-soleils.* This provides an unlimited architectural resource, a key to new architectural riches. Their dimensioning was carefully studied, though their most striking impression lies in the free, strong sculptural effect, masterfully handled. The loggias are painted in varied bright colors which underline the individuality of dwelling units.



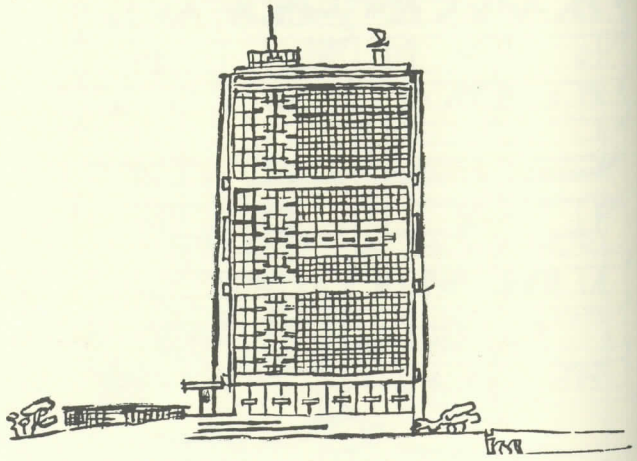


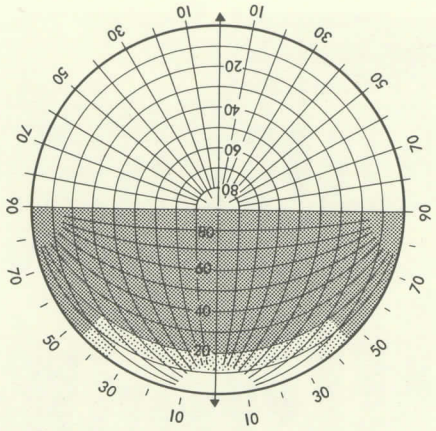




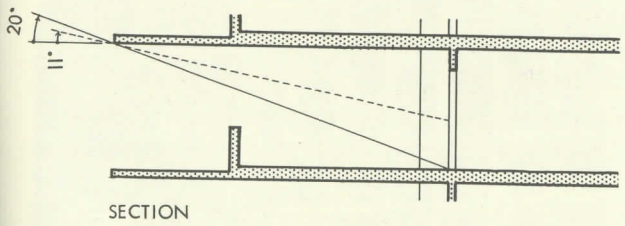
LE CORBUSIER, *Office Building, Algiers, Algeria*

This edifice, planned 500 feet in height, has harmony in all its parts. The plan, as well as the elevations are implacably controlled by the succession of rational requirements, and expressed with plastic sensibility. The plan is rigorously symmetric, the form a pure imperative prism over which a skin of glass is stretched. Before it a "cladding" of sun-breakers is applied in a terrace-like form; the direct rays are arrested, rays reflected from the sea are caught, and the beating of rain on the skin of glass is prevented. Over the purity of the silhouette the graduated and diverse repartition of all secondary elements are formed according to the golden mean.

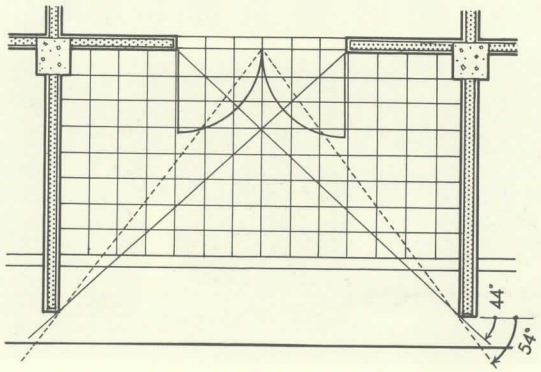




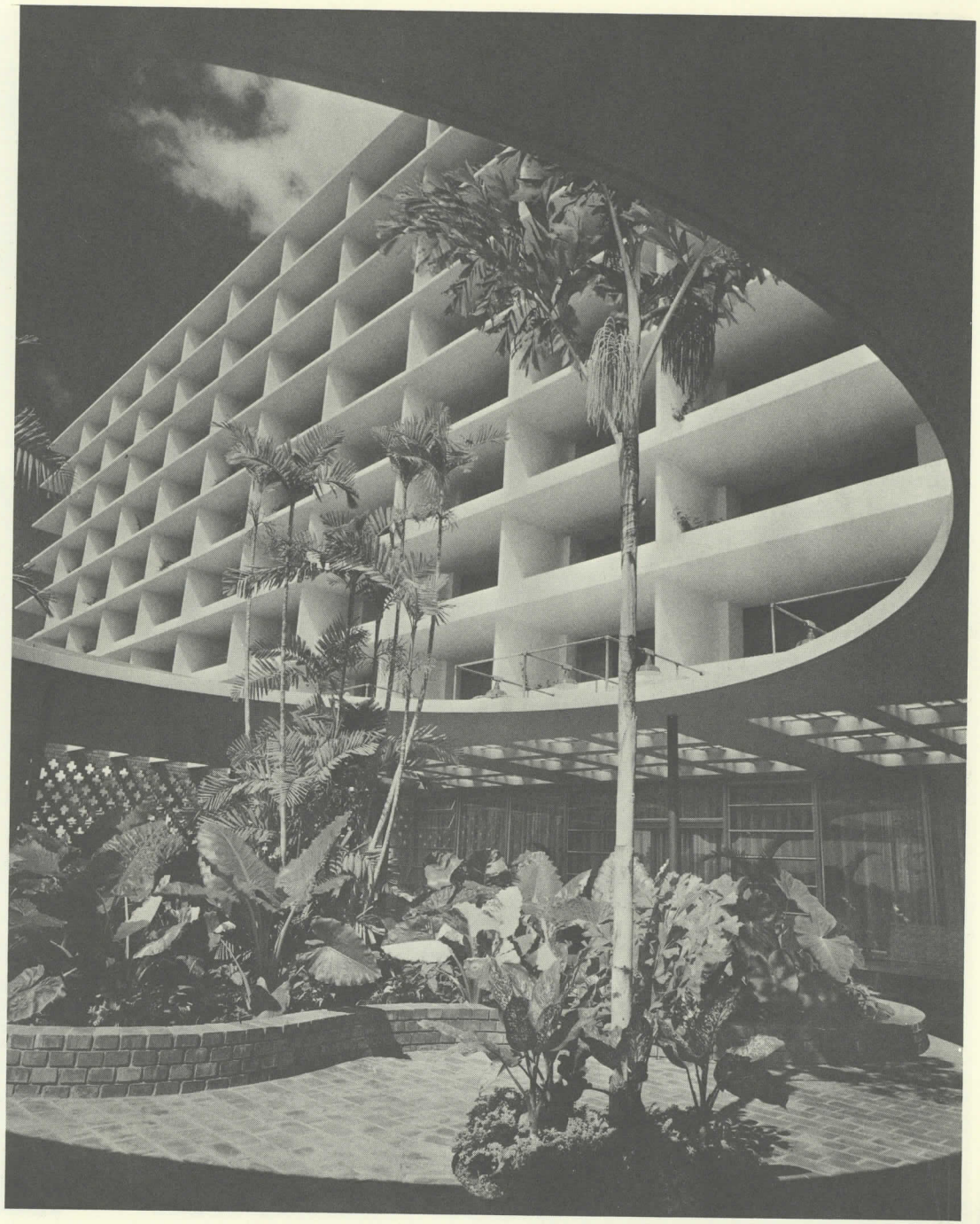
E. D. STONE, *El Panama Hotel, Panama City*
For most of its 450-foot length this tall white honeycomb on the edge of Panama Bay is wide open to the cooling ocean breezes, with more than half of the hotel rooms designed as breeze-ways raised high up into the tropical sky where the trade winds can sweep through them.

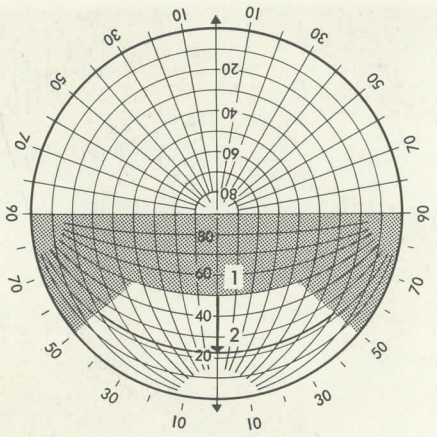


SECTION



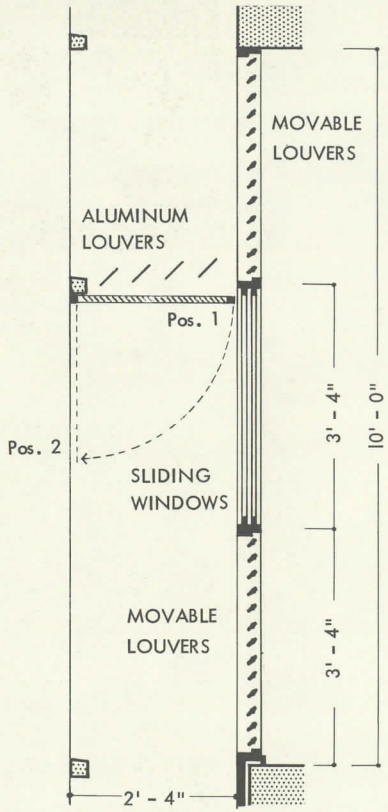
PLAN



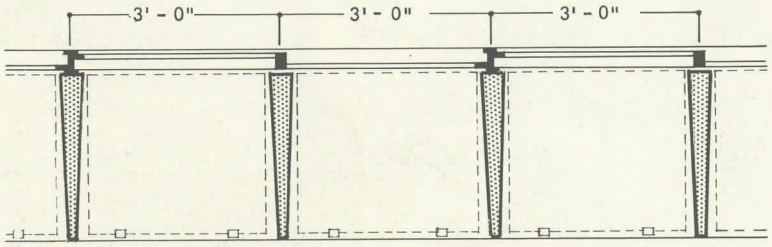


M. M. M. ROBERTO, *Copacabana Apartments, Rio de Janeiro, Brazil*

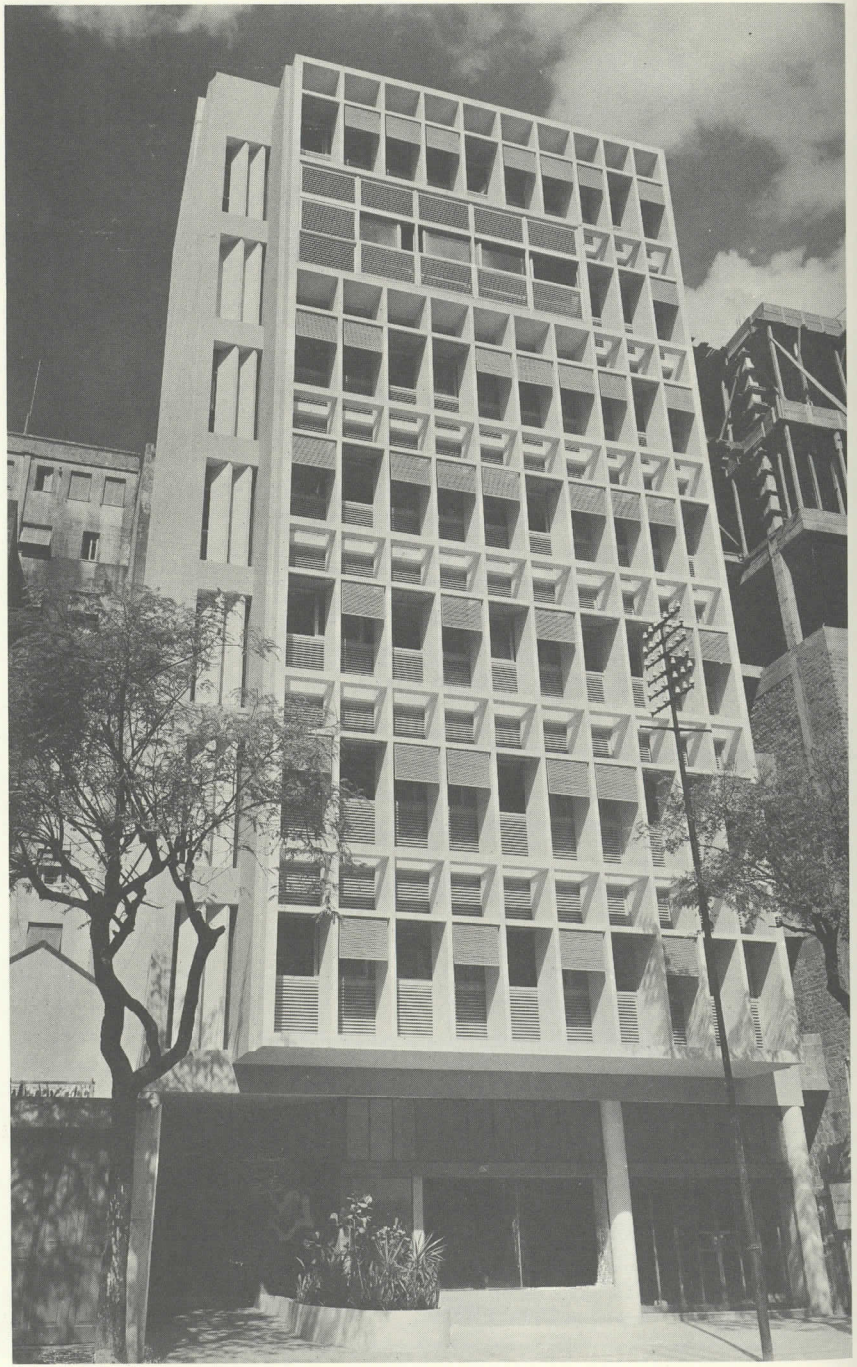
The devices on the front of the building for control of sun and sky glare are the most notable elements of the facade. As shown in the section, an open framework allows a view outward and downward from the living rooms. Fixed horizontal louvers of asbestos cement reduce sky glare, and movable wood jalousies, hinged at the outer frame, cut off late afternoon sun. Above the window head another series of movable louvers extend up to the ceiling line. The result of the organization is a rich interplay of texture and form.

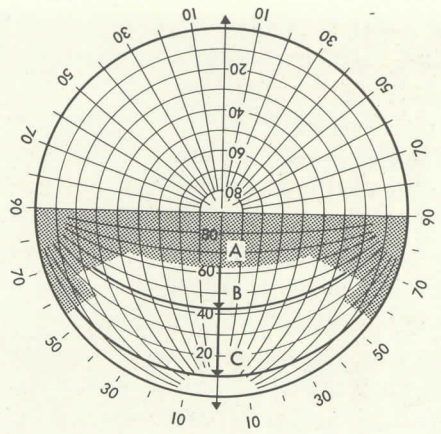


VERTICAL SECTION



HORIZONTAL SECTION THRU VERTICAL FINS

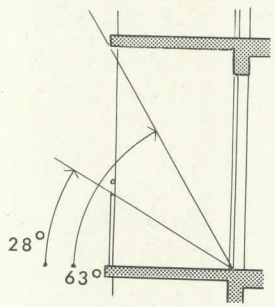




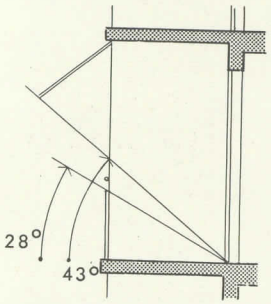
HJALMAR KLEMMING, *Apartment House, Stockholm, Sweden*

Part of the elevation of an apartment house at Karrtorp, Stockholm. The building is a ten-storied "pointhouse," situated among pine trees and enjoying an uninterrupted view above them. The control of the sun is solved with a combination of fixed and movable devices. The fixed elements, as the balcony's floor, the partially solid railing, and the partition walls, give mask "A." According to its position the movable canopy gives the superimposed mask "B" or "C." Only the 100% shading is shown.

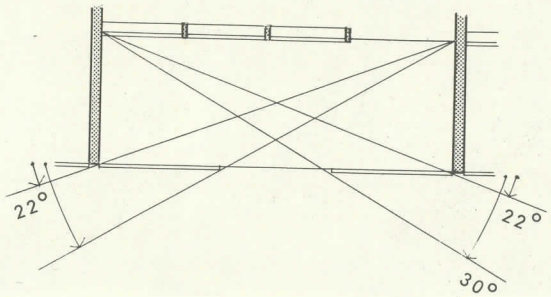
POS. "A"



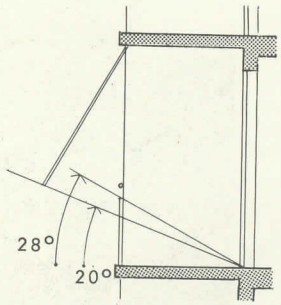
POS. "B"

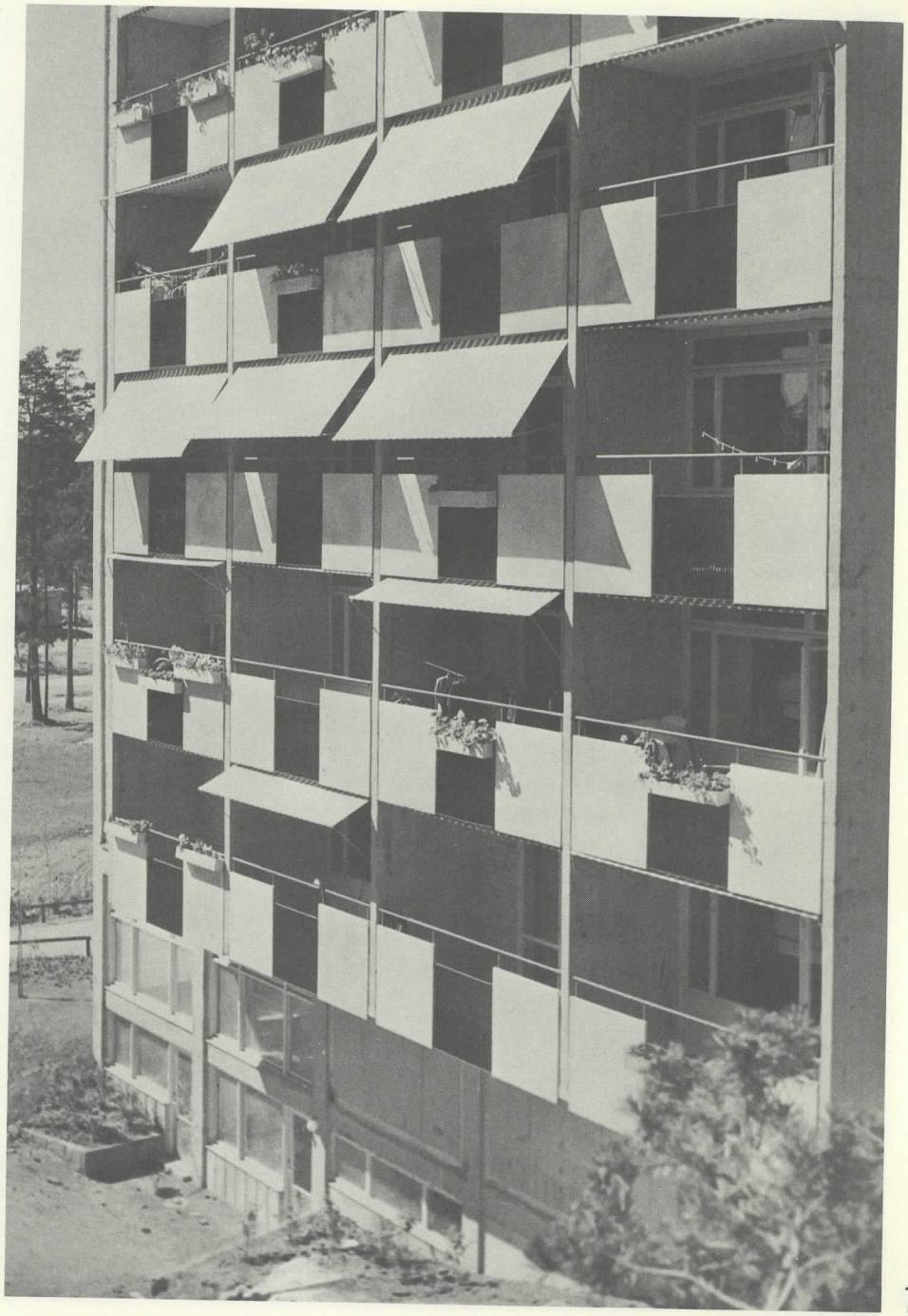


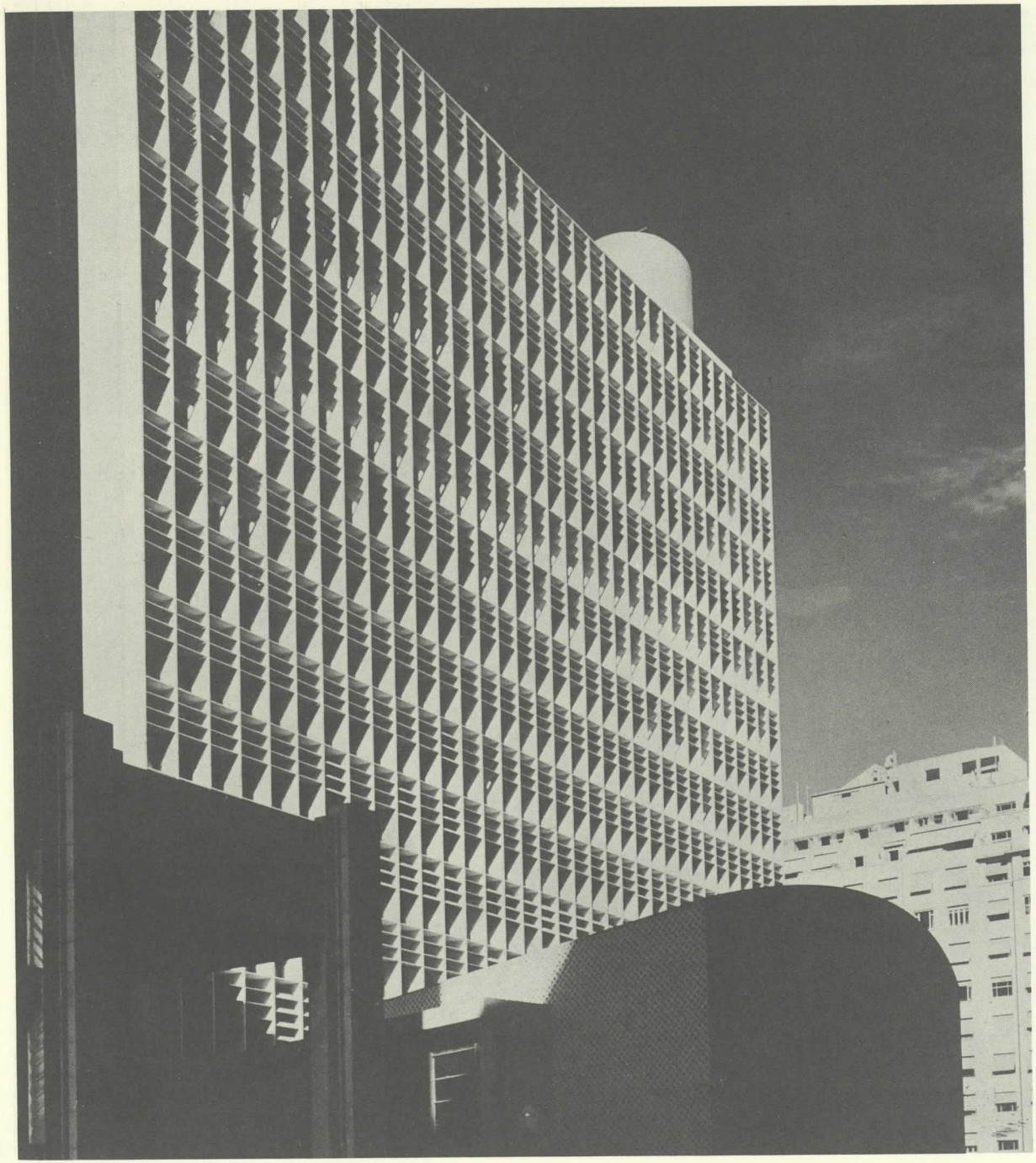
PLAN



POS. "C"





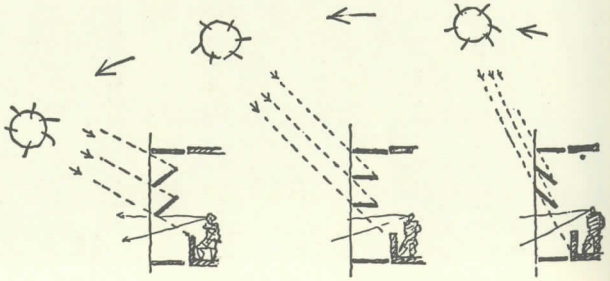


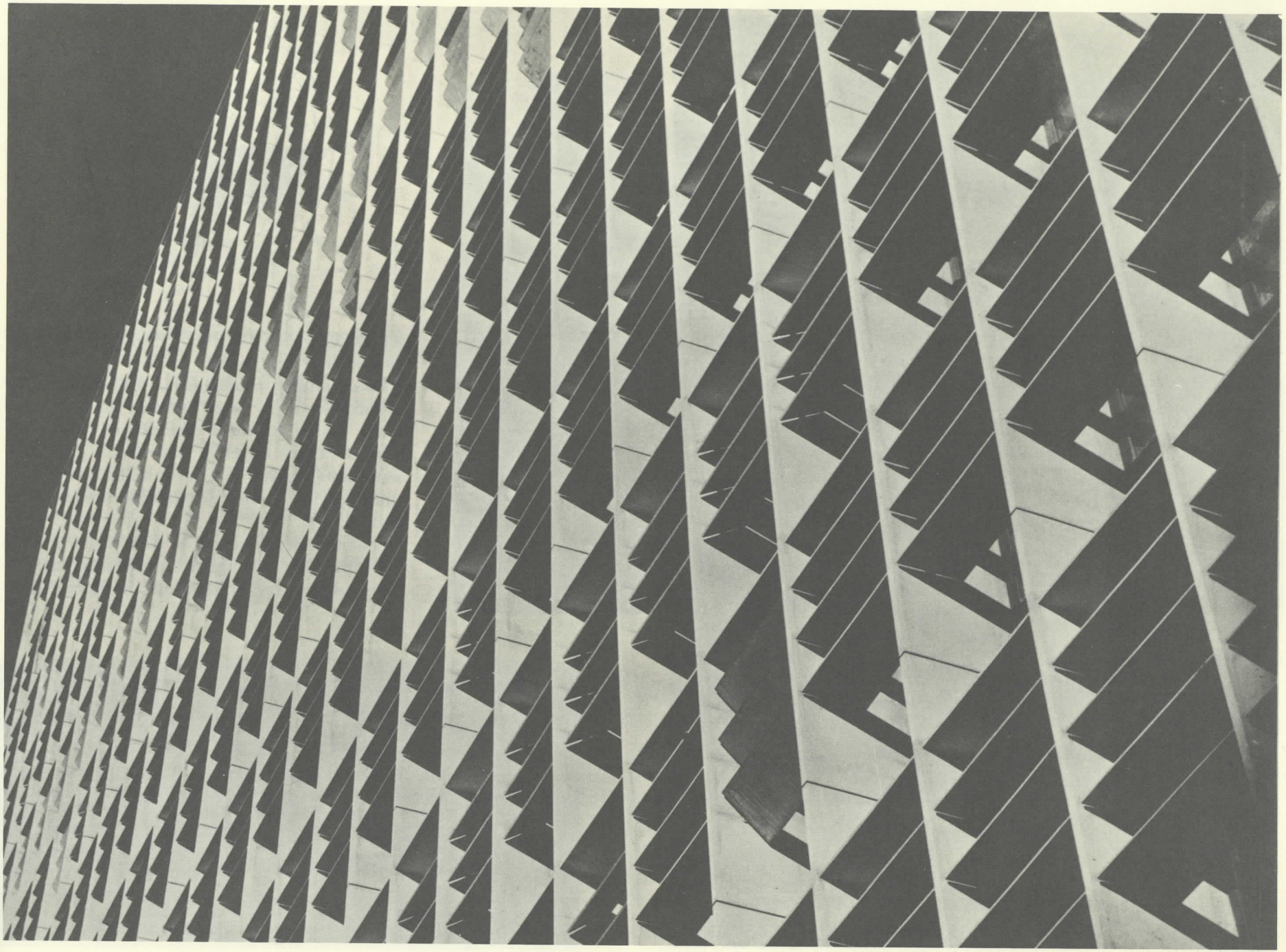
OSCAR NIEMEYER, REIDY, COSTA, & OTHERS, *Ministry of Education, Rio de Janeiro, Brazil*

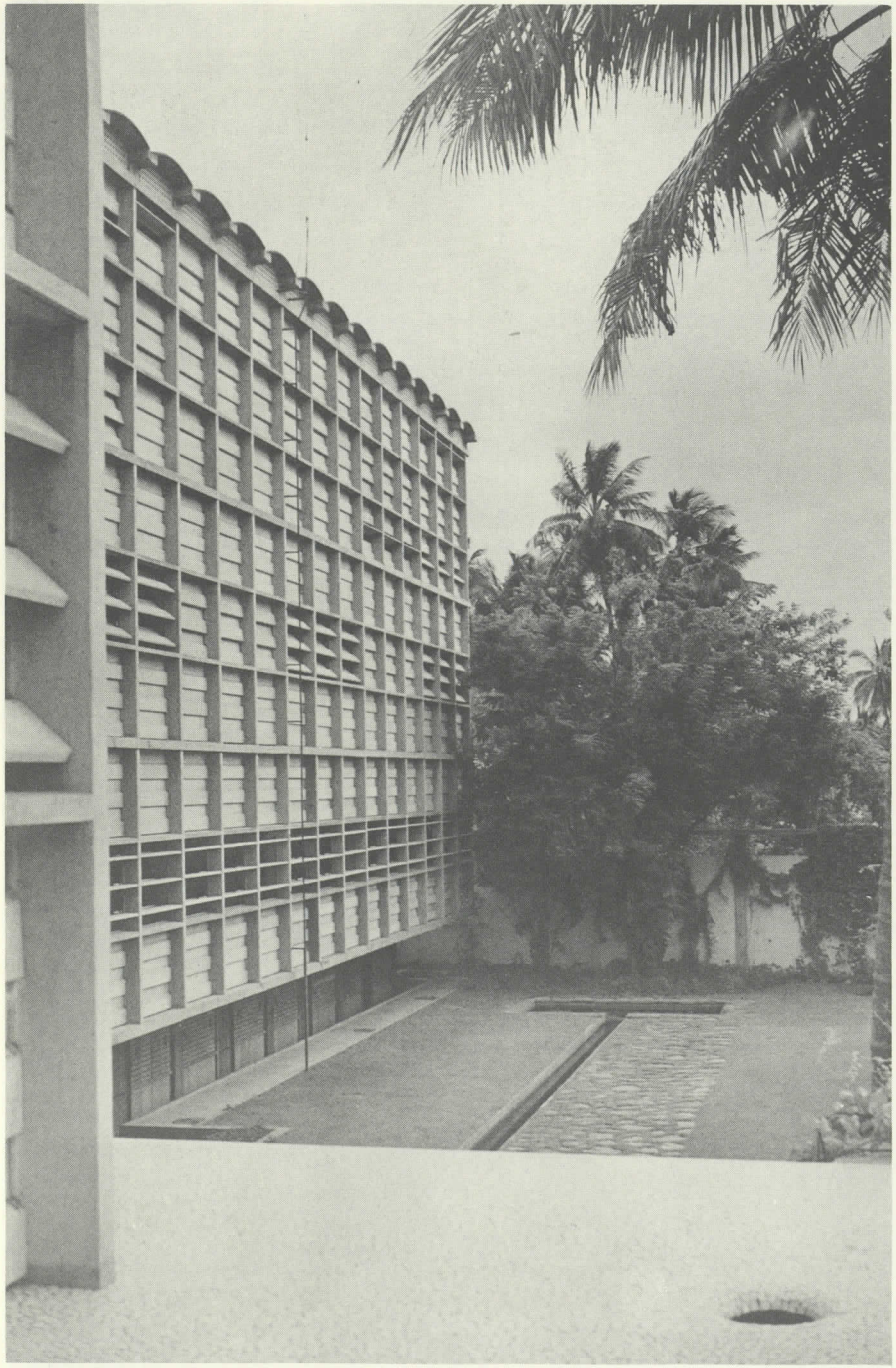
This building, finished in 1943, was the first one which expressed clearly the differentiation in their treatment of the variously oriented surfaces. The group of architects, with Le Corbusier as consultant, created a rich textural expression on the north facade with a daring use of movable eggcrate shading devices.

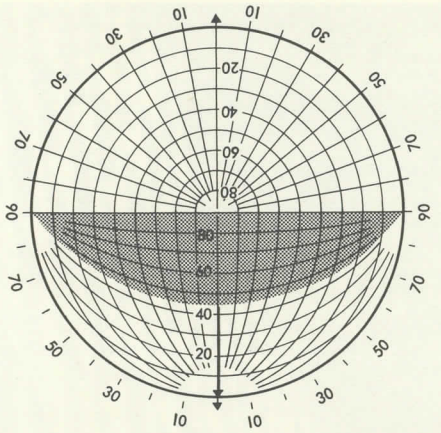
On its east and west elevations the building is closed with a veneer of pink marble. The south facade, which is not exposed to the sun, is entirely of glass. The north facade, which receives a strong insolation in Rio de Janeiro, is covered entirely with a giant sun-shade, which consists of fixed vertical concrete fins, in which three movable panels of thin concrete are connected to a level arm. This arm allows a position dependent upon the incidence of the rays of the sun. The entire system is very close to the form of Persian blinds.

The shading mask of the device is shown on page 5.









ANTONIN RAYMOND, *Pondichery Dormitory, Pondichery, India.*
This dormitory in India is not a building in the ordinary sense, it was designed to provide a space, which is roofed, shaded and ventilated. The elevations therefore consist of a giant Persian blind, which is clearly and sincerely expressed. Here, really the shading device is the architecture.

The two elevations shown have the same basic principle, but are treated differently; the recessed strip gives a contrasting horizontal char-

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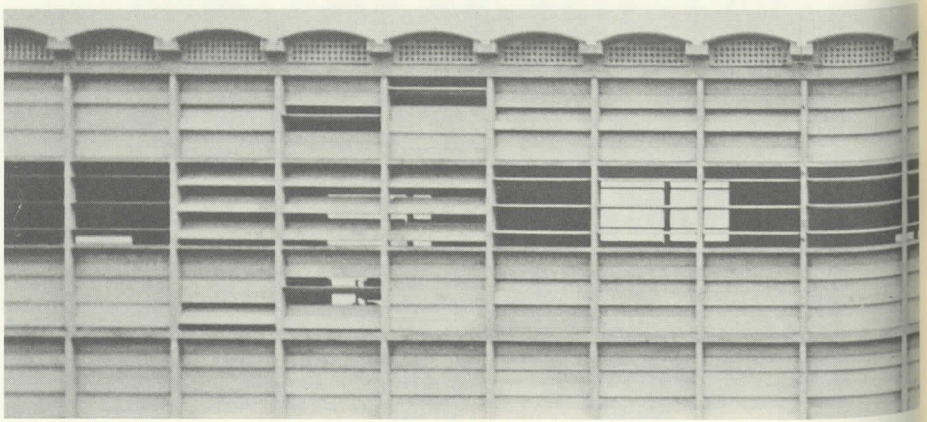
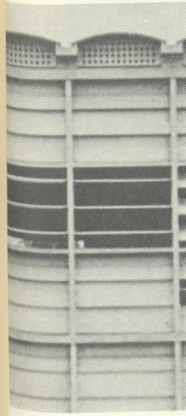
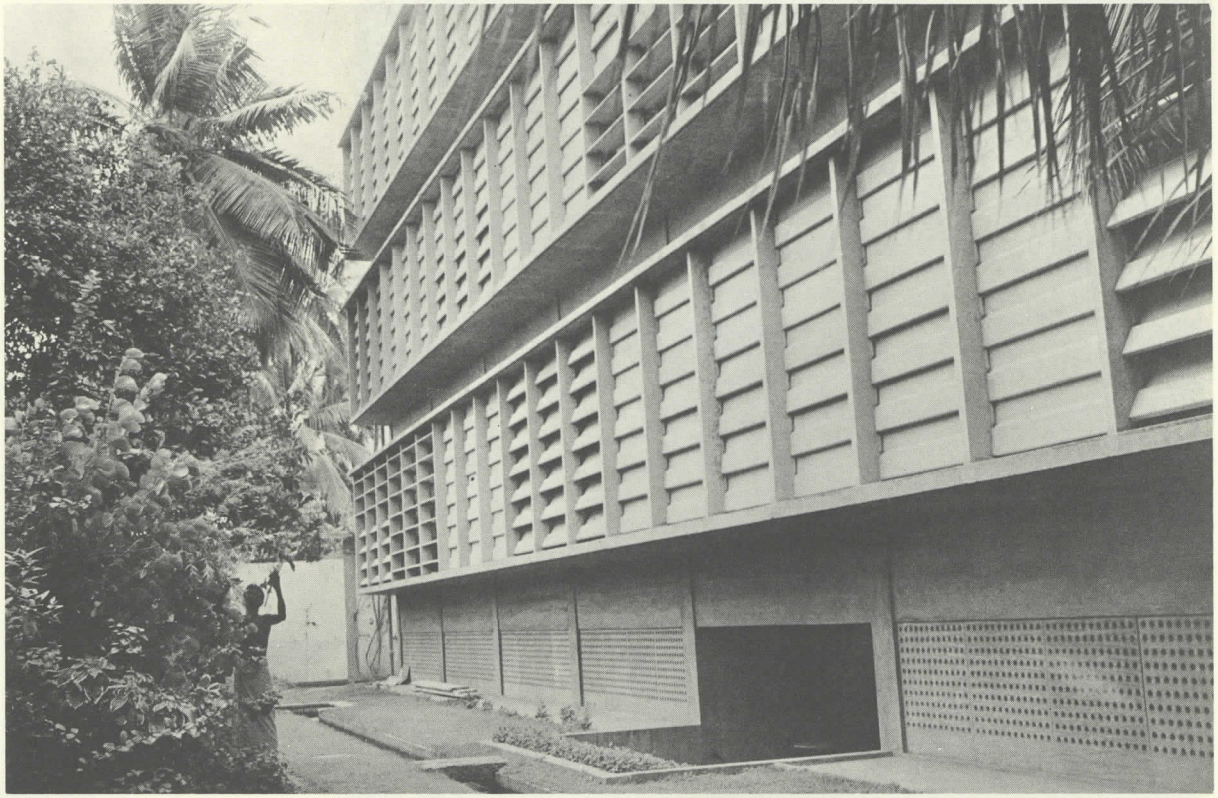
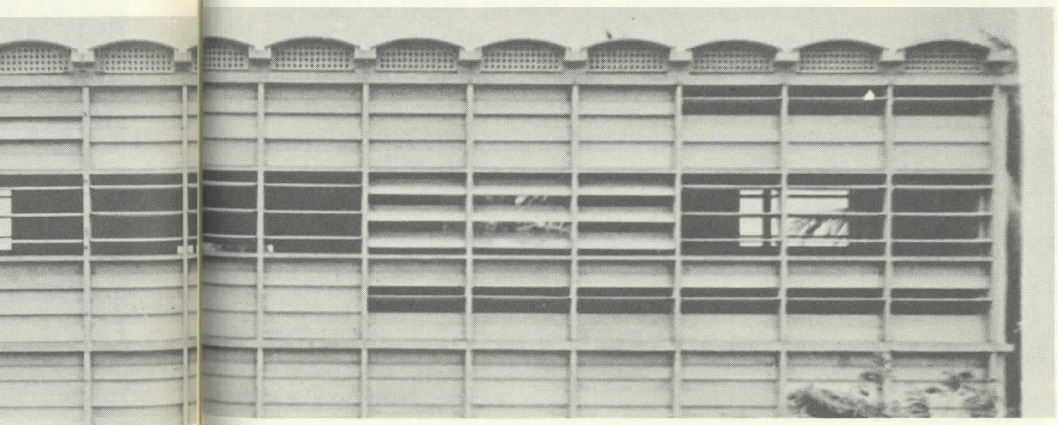


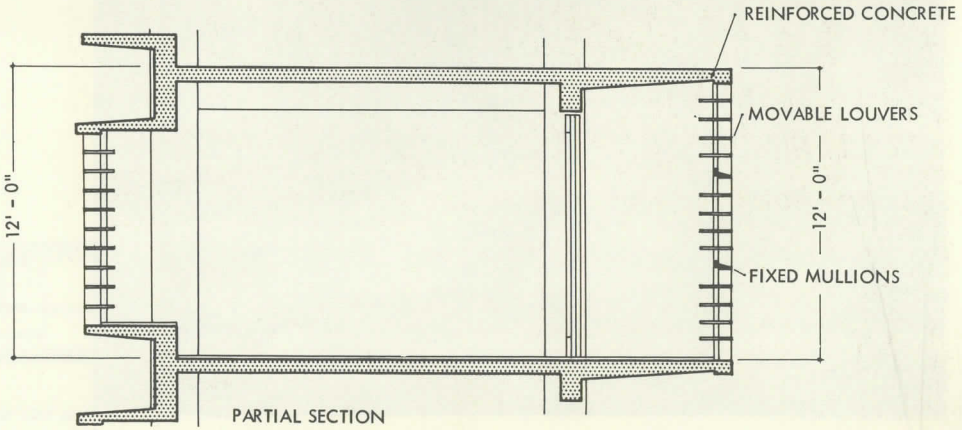




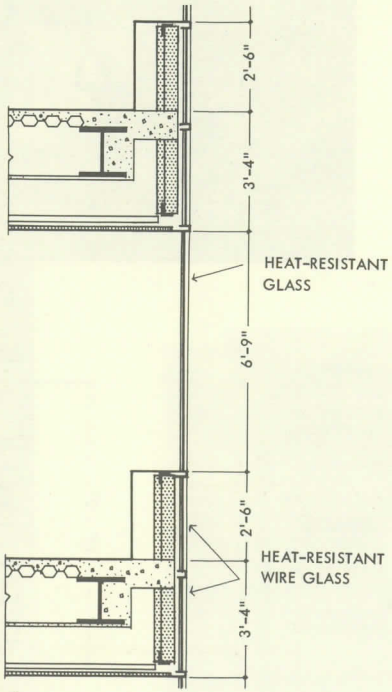
acter, and on the inside provides a sitting alcove.

On both the north and south facades, the entire building surface is equipped with operating horizontal louvers to afford protection from the sun, and from violent wind and rain, while allowing for ventilation. There is no glazing in any portion of the building. High ceilings throughout ensure maximum air circulation. Walls of pierced precast slabs shield the interior from sun. Galleries serve the double function of acting as corridors and creating a deep insolative area in front of the sleeping area.



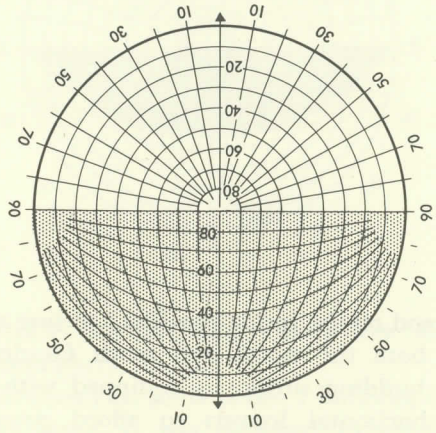


PARTIAL SECTION



WALL SECTION

SKIDMORE, OWINGS & MERRILL, *Lever House, New York, New York*

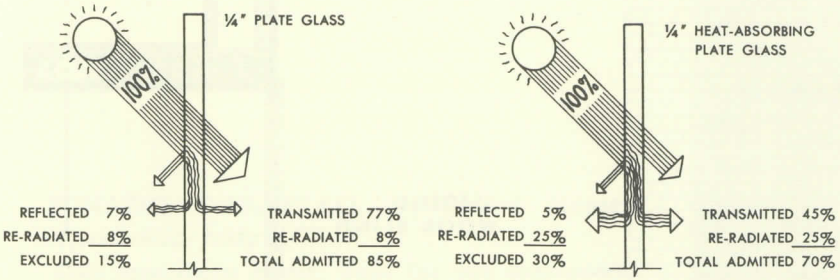


Very often in contemporary design expression, large transparent facades are exposed to solar radiation without application of sun-shading devices. In such cases much care must be taken in the choice and organization of glass for protection from reflection, absorption and transmission of solar heat.

On flat elevations, partial shading can be achieved by the use of heat-absorbing glass, which reduces the amount of heat from the sun that would normally be admitted through ordinary windows. These solutions might be catagorized as a means of shading of which two examples are shown.

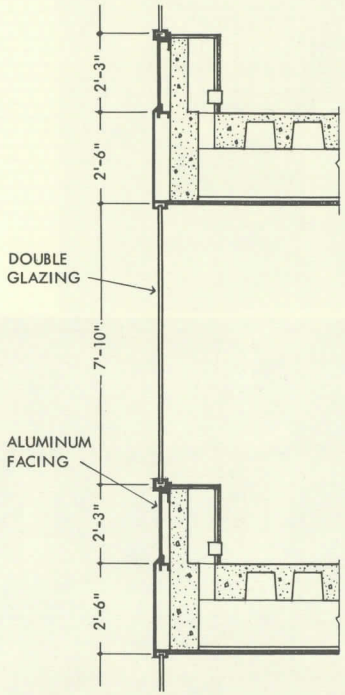
The advantages of heat-absorbing glass can be seen if it is compared with plate glass. In the case of ¼" plate 7% of reflection and 8% of radiation would be excluded. It would admit 77% by transmission and 8% by radiation, thus a total of admitted solar heat would amount to 85%.

PIETRO BELLUSCHI, *Equitable Savings and Loan, Portland, Oregon*

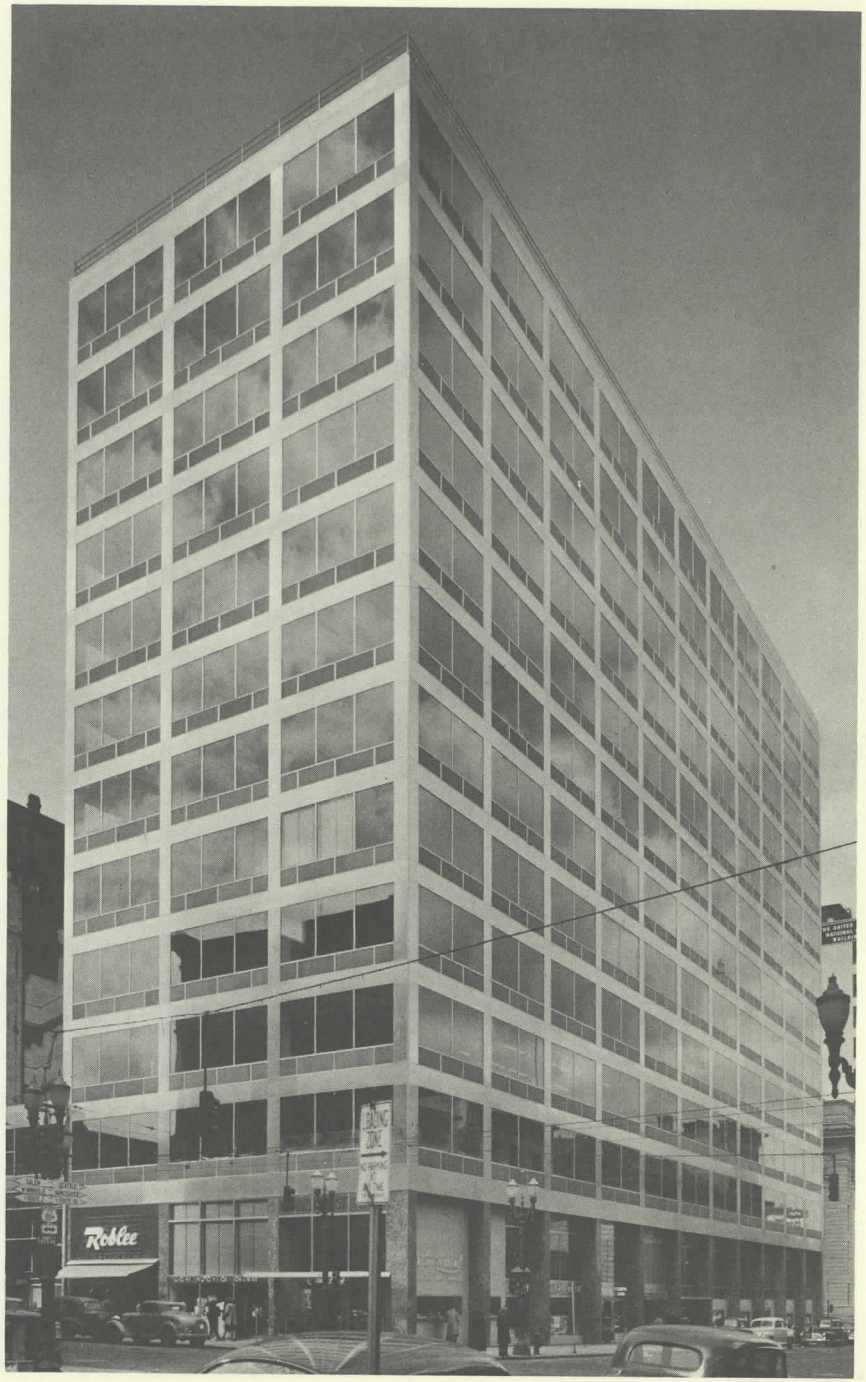


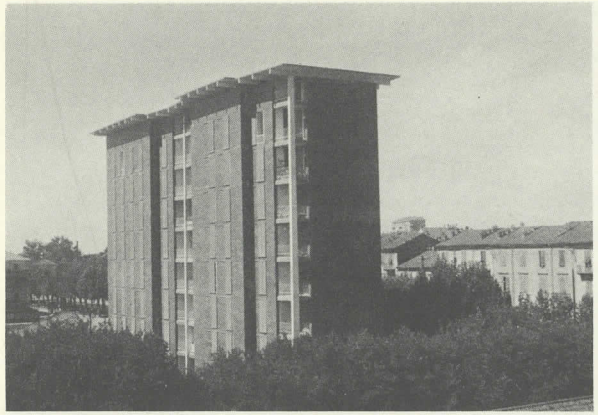
The data for solex for ¼" glass shows a reflective quality of 5% and a re-radiation of 25% and so excludes a total of 30% of the heat energy. It transmits 45% and re-radiates 25% to the interior of the building, with a total of 70%.

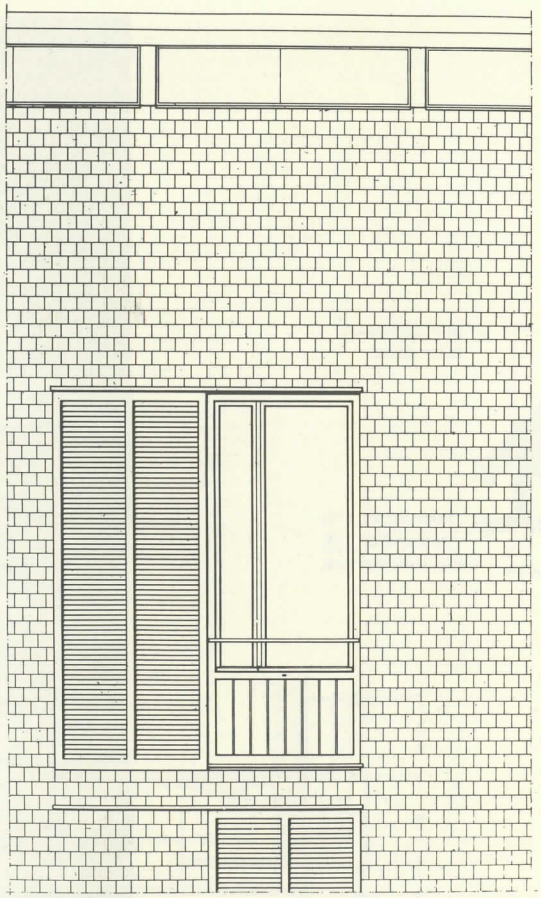
On this page the Equitable Savings and Loan building in Portland is shown. This building provides a visual impact of a huge area of sea-green glass composed of a double glazing of heat-resistant glass. The outer sheet of the sandwich is ¾ inch plate, chosen for its efficiency in reducing the air-conditioning during the intense periods of the summer. Since the heat absorbing glass is 40% more opaque to solar heat than the ordinary plate, its use in a sandwich seems very logical. However this combination was selected only after the architect had satisfied himself that it would not only reduce solar heat but also cut down sky glare to a point where blinds or shades would not be needed for comfort.

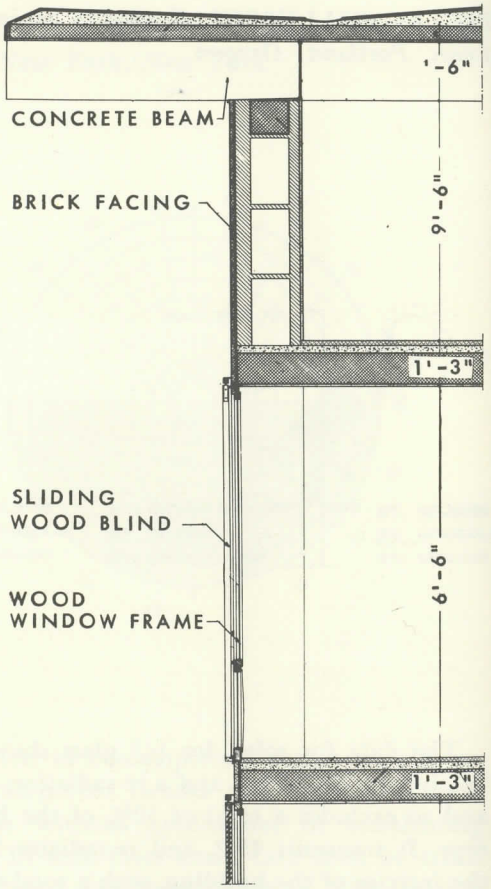


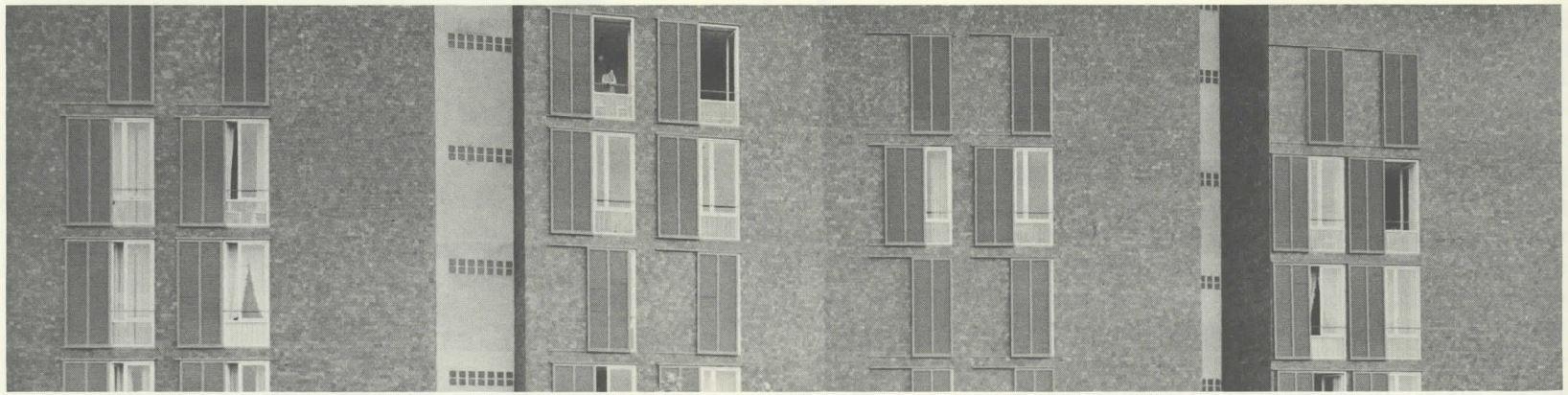
WALL SECTION











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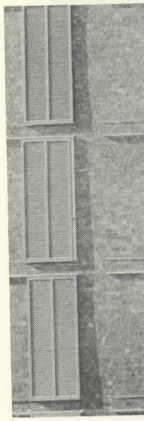
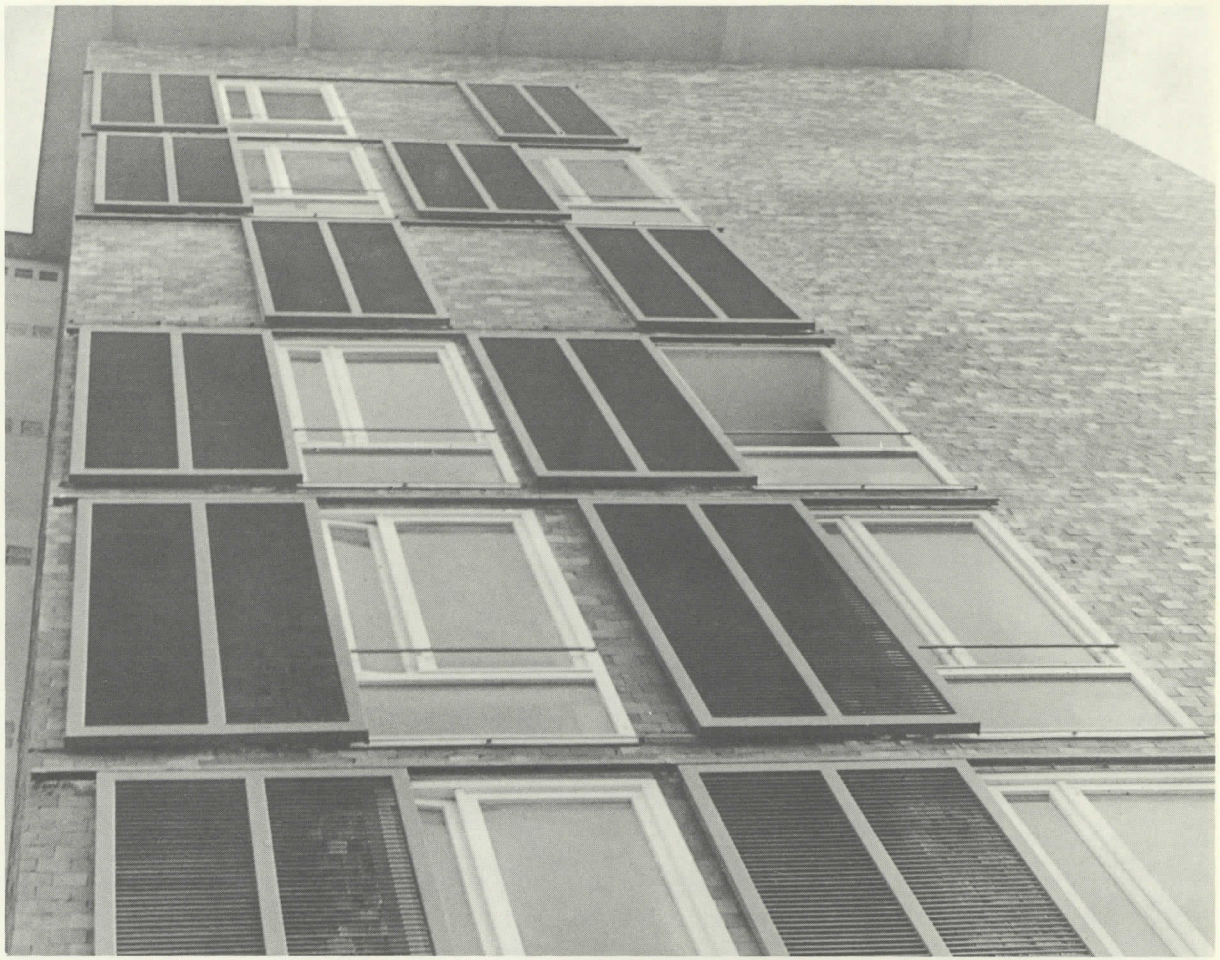
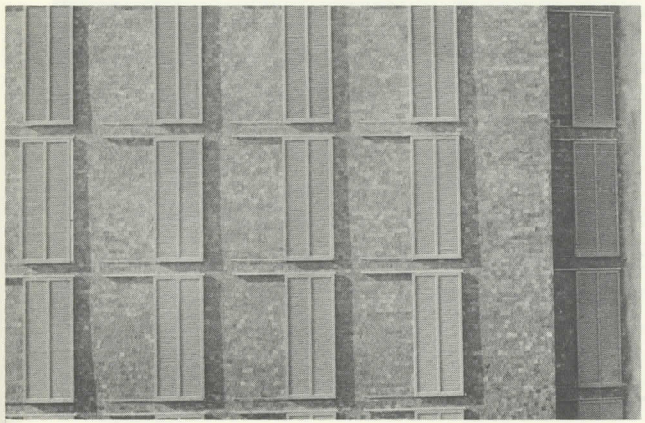


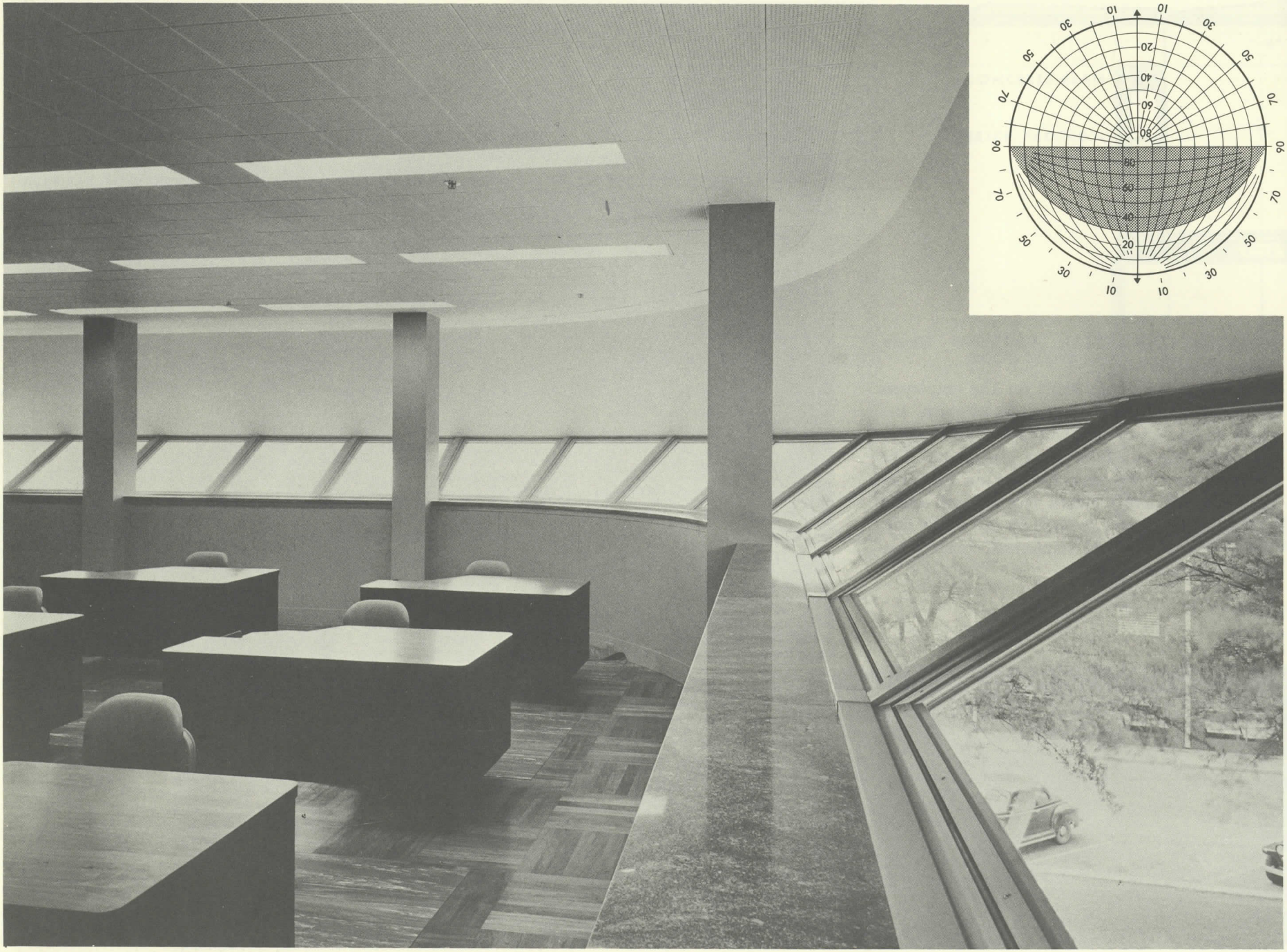
IGNAZIO GARDELLO, *Apartment House, Alessandria, Italy*

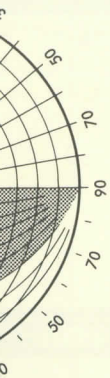
This apartment house, built for the employees of the Borzalino hat factory, faces north and south. It has eight floors, with apartments served with two groups of elevators and stairs. The organization of the plan is based on the principle that all living rooms face toward south; only service areas are situated on the north side. The construction is of reinforced concrete enclosed with brick walls.



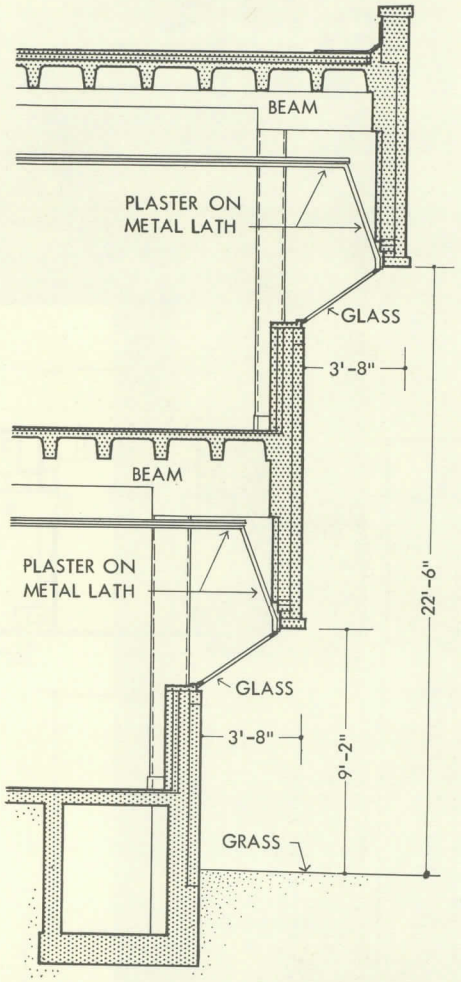


The architectural expression reflects here one of the oldest and well proven methods of sun control: the louvered jalousies. These jalousies are used with a contemporary feeling; they accentuate more the whole surface than each opening separately. This results in an interesting interplay between the closed and open units. The character of the whole building changes with these movements in interesting variations. The jalousies slide on tracks on the exterior surface of the elevation.





ROBERTS & COMPANY, ASSOCIATES,
Springs Cotton Mills, Fort Mills, South Carolina
The glass is so angled as to receive no interior reflections, even at night, and thus gives an illusion of open space. The tightly sealed, perfectly shaded windows, with a relatively small area of glass exposed, save more than 10% in air-conditioning costs compared with a conventionally glazed office space. This permits a temperature control of +1°, humidity control of +2%.



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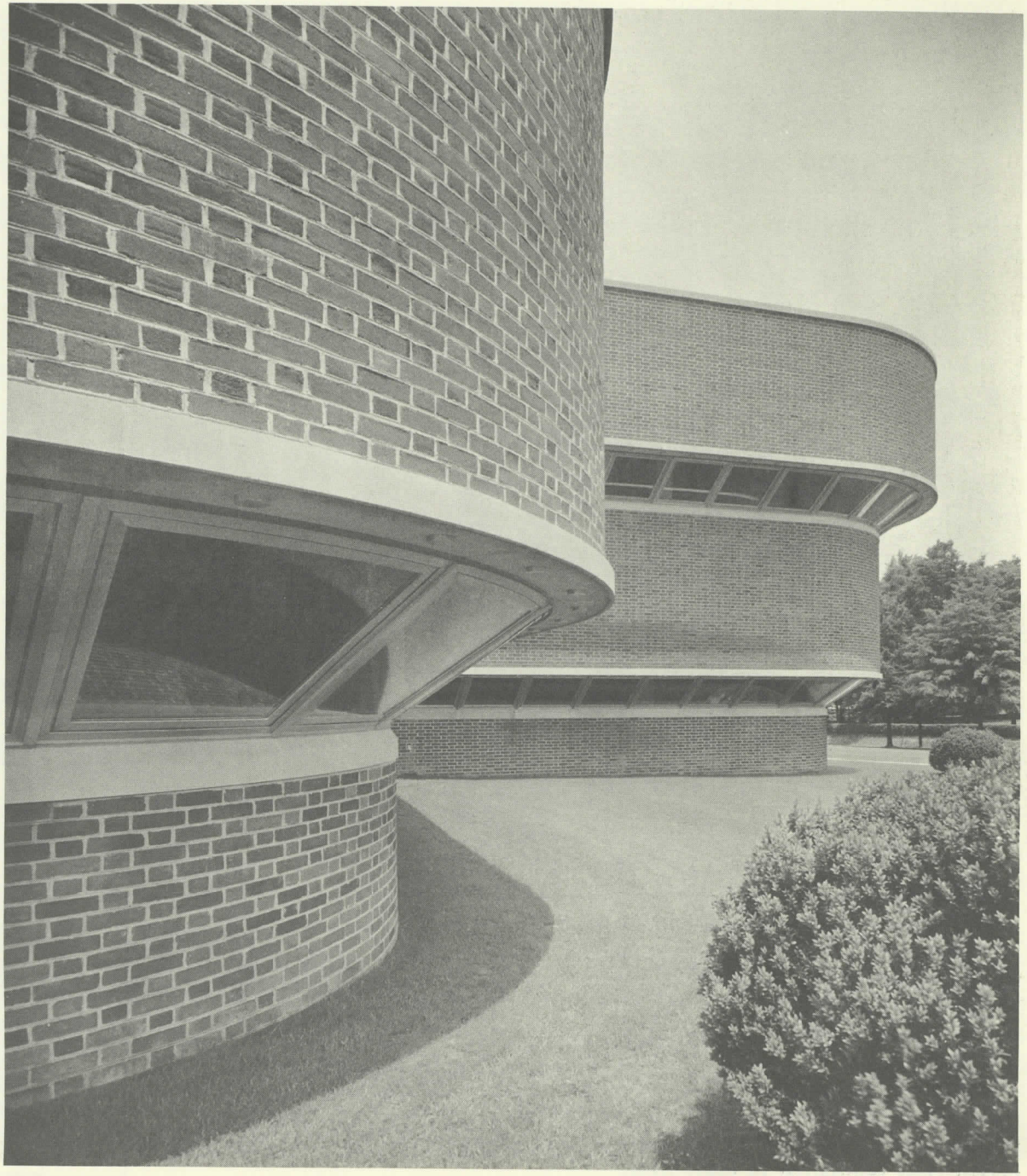
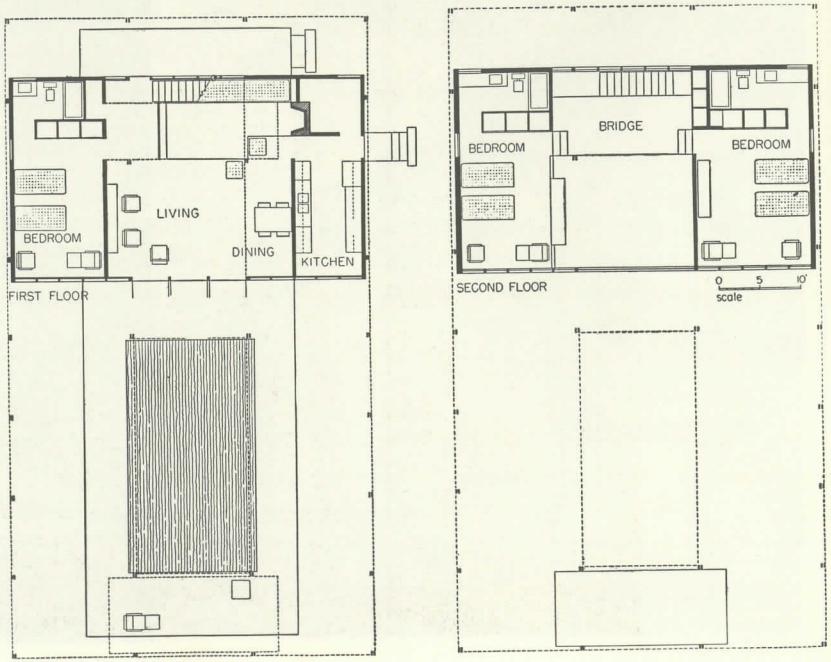
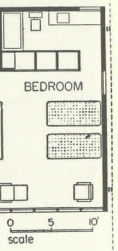




PAUL RUDOLPH, *Hiss Residence, Lido Shores, Sarasota, Florida*

An umbrella structure, which is entirely separate from the building shell, shades the roof, the terraces surrounding the pool, and part of the lot. It is a graceful construction with a charming pattern against the sky. A two-foot separation between the parasol and the roof of the house allows an air space which is shaded, thus reducing heat intensity. The slat roof construction allows a free movement of air up and out from the parasol. The living unit has front and rear walls of glass jalousies which permit cross ventilation in every room.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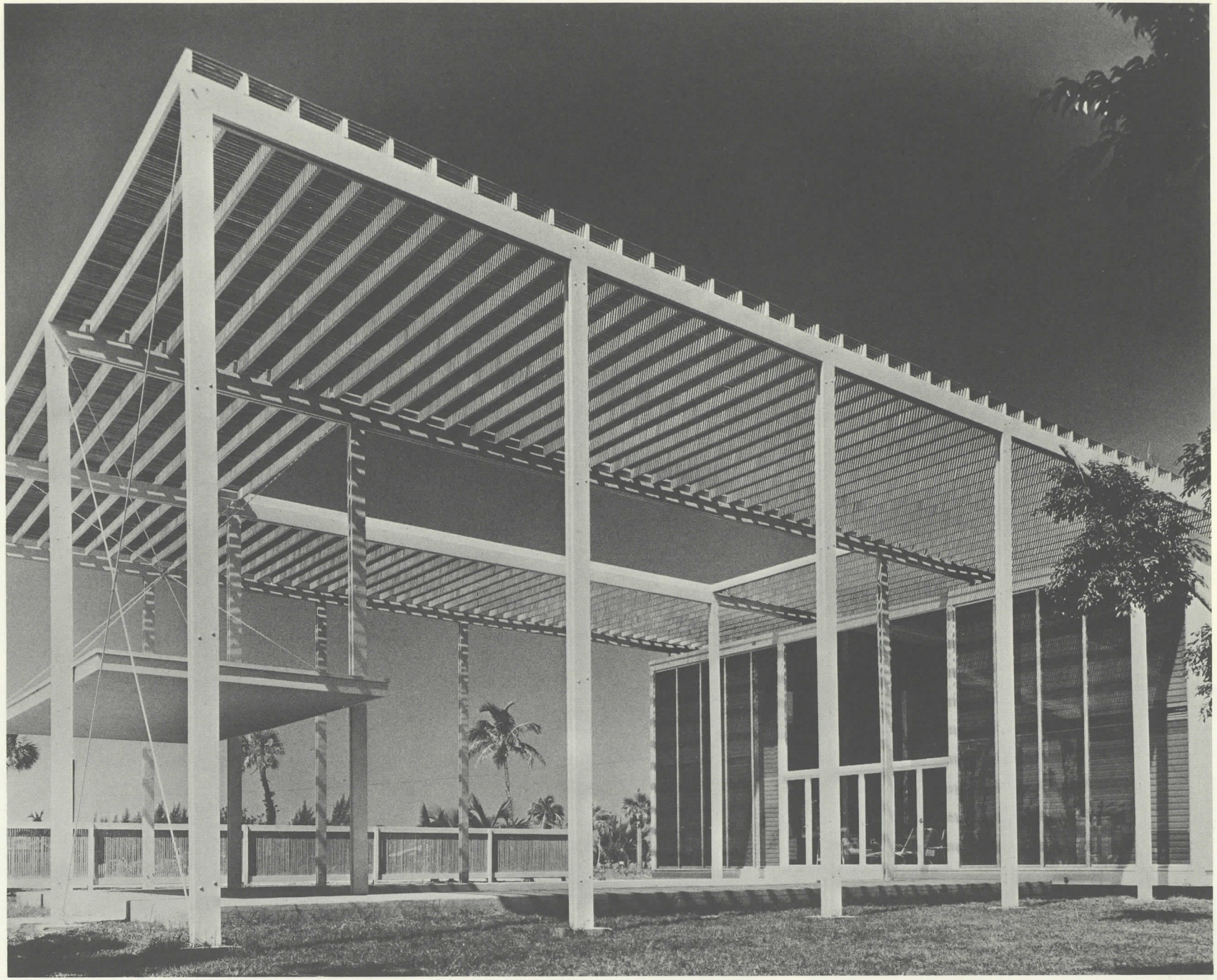
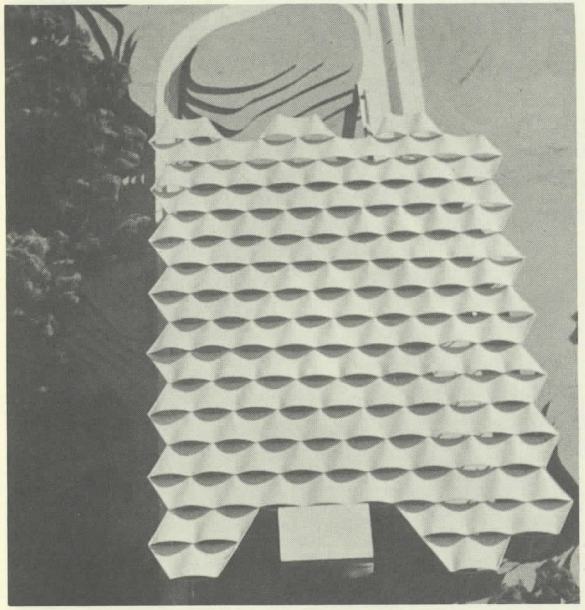
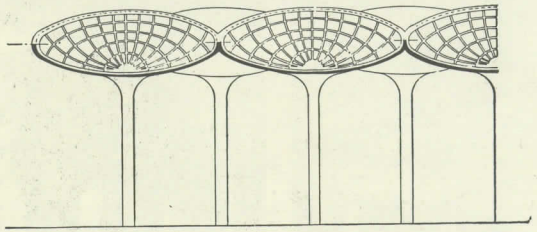


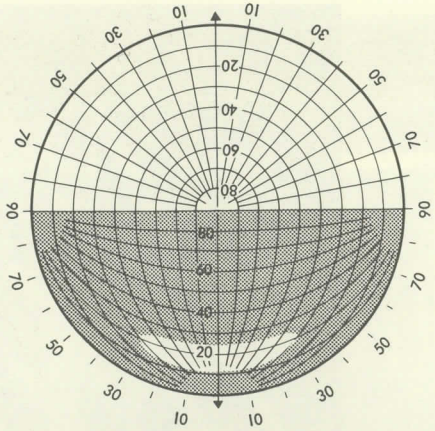


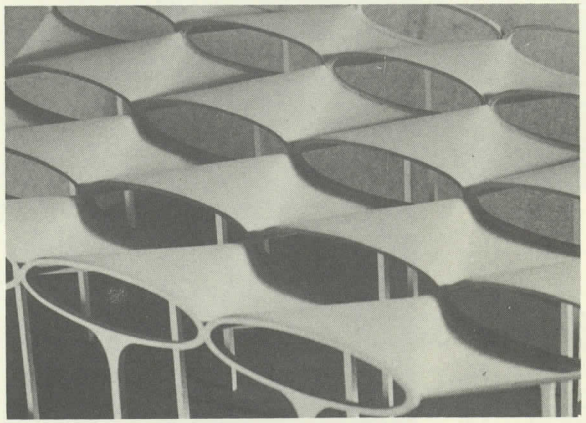


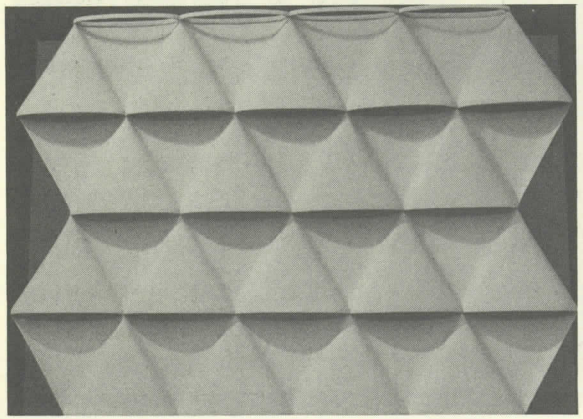
HORACIO CAMINOS, *University of Tucuman, North Argentina*

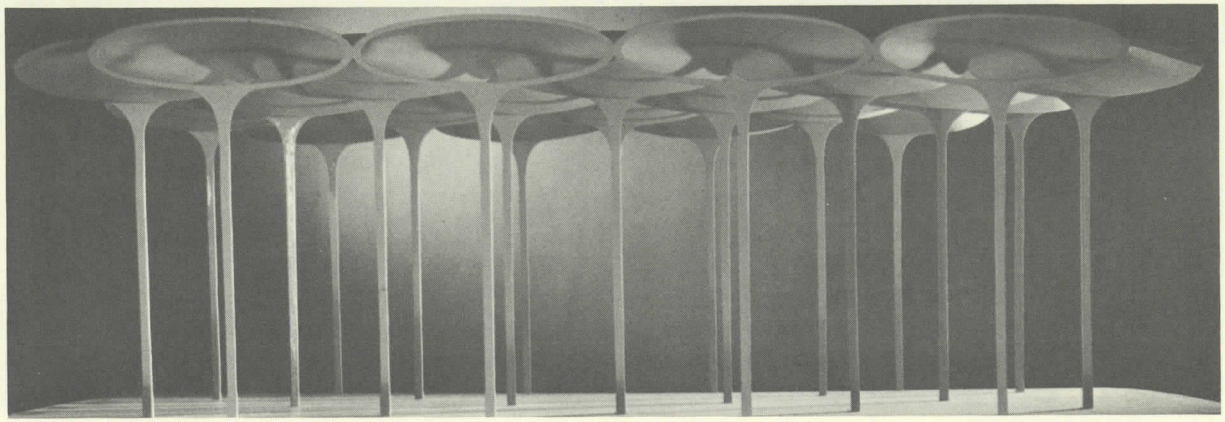
This ingenious solution of sun control provides an open space for community center activities. The structure is a covering, much like a great umbrella, which shelters shops and entertainments. Its integration is appropriate in a region where people live most of their lives out of doors, and only an overhead protection is needed for shade and occasional rains. The flexible structure accommodates the heterogeneous elements of the program and also the differences of aesthetic expressions of the shopkeepers, yet still provides a space of architectural dignity. It was planned to build something that would grow and spread elastically like an ink spot without losing its unity.

The umbrella roof consists of a thin shell of reinforced concrete units, and it can be expanded in any direction. The shells are protected against rain with glass and are open to the north, thus avoiding sun in the summer; but as soon as the season advances and the cool days begin, the sun-rays gradually go through the roof more and more until we reach winter. Then, the whole "plaza" enjoys the warm sun at a maximum. The latitude is 27° south.









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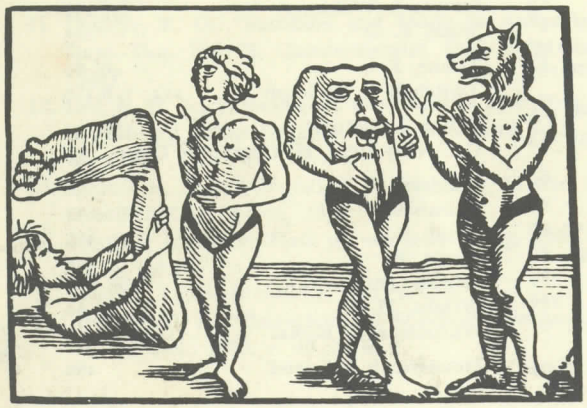

Pliny and Solinus, had admitted into their geographical accounts legends of strange tribes of monstrous men, strangely different from normal humanity. Among these may be mentioned the Sciapodes, or men whose feet were so large that when it was hot they could rest on their backs and lie in the shade.

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